Standard Operating Procedures for Tracking & Accounting of Natural Resources Restoration Projects

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Natural Resources Restoration Tracking & Accounting Summary

Project Type	Definition and Practice Standards	Data Requirements	Area Treated Definition	Total Phosphorus Load Reduction Efficiency	Design Life
Forested Riparian Buffer Restoration	Restoration of riparian buffer along rivers and lakeshores. Buffers consist of native woody vegetation (trees and shrubs) with a minimum of 300 stems per acre and a minimum width of 35-feet.	Latitude & longitude Buffer acres Buffer length Buffer average width Land uses in drainage area	5x buffer area	40% plus land use conversion to forest	20 years
Bioengineered Shoreline Stabilization	Implementation of shoreline stabilization practices using a combination of biodegradable materials and vegetative plantings to naturally stabilize slopes.	Length of shoreline Average bank height Average shoreline recession rate	Erosion volume prior to restoration	85%	10 years
Forest Road and Trail Erosion Control	Implementation of forest logging road, trail, and/or stream crossing Acceptable Management Practices (AMPs) project(s) to address erosion to control nutrient and sediment pollution.	County Road segment runoff potential, slope, soil type, road type, buffer gradient, and distance from waterbody Road erosion inventory (REI) compliance scores before and after restoration	Road segment length (100 m)	Not compliant → partially compliant: 40% Partially compliant → fully compliant: 40% Not compliant → fully compliant 80%	5 years or REI reassessment (whichever is sooner)
Use Value Appraisal Enrollment	Enrollment of private forestry land in the Use Value Appraisal (UVA) Program which requires implementation of the Acceptable Management	SPAN number Enrolled forestland acres Enrollment year	Enrolled acres	80%	10 years

Project Type	Definition and Practice Standards	Data Requirements	Area Treated Definition	Total Phosphorus Load Reduction Efficiency	Design Life
	Practices (AMPs) to the maximum practicable extent.				
Stream and Floodplain Restoration Wetland Restoration	Restoration of river channel and or floodplain to its least erosive condition (i.e., equilibrium condition). Restoration work includes removing/retrofitting river corridor and floodplain encroachments and instream structures, dam removal, and establishing river corridor easements. Implementation of wetland and buffer area restoration and protection projects to promote water quality benefit, encourage flood resiliency, and provide habitat benefits.	Subunit ID Subunit river corridor acres / length of stream Stream Subunit connectivity allocation Subunit connectivity scores before and after restoration Size/operation of structure removed/replaced/retrofitted Subunit acres/length restored and/or protected	Subunit river corridor acres and/or length of river restored	Varies by project type and connectivity scores	10 years for active restoration projects 40 years for passive restoration projects

Introduction

While many of Vermont's surface waters are high quality, several surface waters suffer from non-point source pollution in the form of excess sediment and phosphorus from the landscape. The State of Vermont is covered by several large-scale Total Maximum Daily Load (TMDLs), or restoration plans that identify pollutant reductions required for an impaired waterbody to meet the State of Vermont's water quality standards. The Lake Champlain and Lake Memphremagog TMDLs target phosphorus pollution which can lead to toxic cyanobacteria blooms, while the five-state Long Island Sound TMDL targets nitrogen pollution causing hypoxia in the Sound.

The US Environmental Protection Agency (EPA) approved the *Phosphorus TMDLs for the Vermont Segments of Lake Champlain* in 2016 (US EPA 2016). The Lake Champlain TMDL contains an Accountability Framework which requires the State of Vermont to track investments and progress towards achieving TMDL targets. The Vermont Clean Water Act (Act 64 of 2015) and Clean Water Service Delivery Act (Act 76 of 2019) both establish that funding be allocated to clean water efforts and require the state to track and report on all clean water projects across land use sectors. Act 76 of 2019 requires the state to publish methods for estimating phosphorus reductions for all clean water project types in the Lake Champlain and Lake Memphremagog basins.

The Vermont Agency of Natural Resources Department of Environmental Conservation (DEC) is leading the effort to develop and implement methods for tracking nutrient load reductions from clean water projects across all land use sectors. Natural resource restoration projects restore and protect natural infrastructure (e.g., floodplains, river channels, lakeshores, wetlands, and forest lands) and their functions that prevent and abate nutrient and sediment pollution. DEC collaborated closely with the Vermont Department of Forest, Parks, and Recreation and academic researchers to develop methods for tracking nutrient reductions from natural resources restoration projects. The purpose of this document is to outline the current methods used to track and account for total phosphorus load reductions from natural resource restoration projects in the Lake Champlain and Lake Memphremagog watersheds.[1] This document is intended to be updated as new information becomes available or if new research is conducted. DEC plans to review methods in this document for accuracy at least every five years but it could be updated more frequently. All methods are subject to change. TMDL Tracking & Accounting

[1]Total phosphorus load reductions cannot yet be estimated for practices outside of the Lake Champlain and Lake Memphremagog basins. This document does not include methods for estimating total nitrogen load reductions in the Connecticut River watershed draining to the Long Island Sound.

Practice Tracking

Natural resources restoration projects are implemented through numerous funding programs administered by several agencies and organizations, including:

1. Vermont Department of Environmental Conservation
2. Vermont Department of Forest, Parks, and Recreation
3. Vermont Fish and Wildlife Department
4. Vermont Housing and Conservation Board
5. Lake Champlain Basin Program

DEC obtains natural resources restoration project data from both internal programs and partners annually for legislative and EPA reporting in the *Clean Water Initiative Annual Performance Report*. DEC compiles and manages all clean water project data tracked through state and federal funding and regulatory programs using the Clean Water Reporting Framework (CWRF). CWRF utilizes BMP Accounting and Tracking Tool (BATT) to estimate total phosphorus load reductions associated with the implementation of various clean water projects.

Phosphorus Accounting

Clean water projects target nutrient and sediment pollution reductions to improve water quality of Vermont's waterbodies over the long term. While measured water quality parameters are the ultimate indicator of progress, it will take time for Vermont's waters to realize the benefits of clean water projects. To provide incremental measures of accountability, DEC estimates the pollutant reductions associated with clean water projects installed across state and federal funding programs and regulatory programs in Vermont.

Total phosphorus load reduction is estimated based on modeling the clean water project-type, as measuring phosphorus load reductions at the project level through water quality monitoring would be cost-prohibitive. Most clean water project phosphorus load reduction estimates are based on the following:

1. Estimated baseline total phosphorus load from land area prior to treatment by a practice. This is based on the area of land draining to the practice, or the practice area, and the average phosphorus loading rate from the land use. Baseline phosphorus loading rates for each land use, soil type, and field slope combination are obtained from the TMDL SWAT model results (Tetra Tech 2015a).
2. Estimated annual pollutant reduction performance – referred to as an "efficiency" – of the practice type. This is often expressed as a percent of total load reduced and is based on research of project performance relevant to conditions in Vermont.

Phosphorus load reductions are the product of the baseline phosphorus load for the area treated by the practice and the practice phosphorus reduction efficiency (Figure 1). The phosphorus load reduction efficiency is applied starting on the practice implementation date and continues for the expected design life of the practice. In all cases, results of accounting methodologies should only be referred to "total phosphorus load reduction estimates" because phosphorus load reductions were not directly measured.

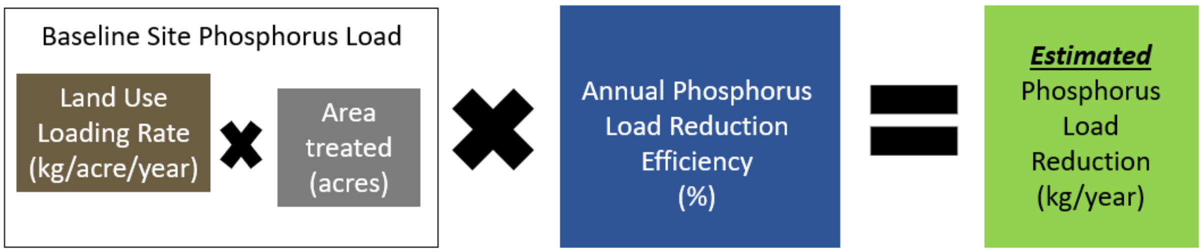

Figure 1. General methodology used to estimate phosphorus reductions from clean water projects.

Weighted Average Loading Rates

The Lake Champlain TMDL Soil Water Assessment Tool (SWAT) model, which was used to determine baseline and target phosphorus loading to Lake Champlain, contained the following loading rate categories applicable to this SOP with individual loading rates for combinations of drainage area, hydrologic soil group, and slope (Tetra Tech, 2015a).

- Generic agricultural land
- Corn-hay rotation on clayey soils
- Corn-hay rotation on non-clayey soils
- Continuous corn on clayey soils
- Continuous corn on non-clayey soils
- Continuous hay
- Pasture
- Mixed forest
- Evergreen forest
- Deciduous forest
- Residential – Low Density (Pervious & Impervious)
- Residential – Medium Density (Pervious & Impervious)
- Residential – High Density (Pervious & Impervious)
- Industrial Commercial (Pervious & Impervious)
- Roads – Paved (Impervious)
- Roads – Unpaved (Impervious)

DEC developed five new area weighted and weighted average (WA) loading rate categories for land uses in the Lake Champlain basin: Cropland WA, Corn WA, Forest WA, Developed Impervious WA, and Developed Pervious WA. These new loading rates were developed to simplify the data requirements for practice tracking and accounting.

Area-weighted loading rates (kilograms per acre per year) were calculated by dividing the total phosphorus load for all the land use types defined for that weighted average by the total area of that land use for each drainage area (major river basins within each lake segment basin) within the Lake Champlain basin. Weighted averages were computed for both individual HSG and slope combinations, and also for an aggregated HSG and slope value to use when HSG and slope data are unavailable. The following loading rates are used for TMDL reporting in the Lake Champlain basin. All loading rates vary by drainage area, soil type (if available), and slope (if available).

- <u>Cropland WA</u>: Area-weighted and weighted average for generic agricultural land, corn-hay rotation on clayey soils, corn-hay rotation on non-clayey soils, continuous corn on clayey soils, continuous corn on non-clayey soils.
- <u>Corn WA</u>: Area-weighted and weighted average for continuous corn on clayey soils and continuous corn on non-clayey soils.
- <u>Forest WA</u>: Area-weighted and weighted average for mixed forest, evergreen forest, and deciduous forest.
- <u>Pasture:</u> Unchanged from TMDL model.
- <u>Developed Impervious WA</u>: Area-weighted for Industrial Commercial (Impervious), Residential – High Density (Impervious), Residential – Medium Density (Impervious), and Residential – Low Density (Impervious)
- <u>Developed Pervious WA</u>: Area-weighted for Industrial Commercial (Pervious), Residential – High Density (Pervious), Residential – Medium Density (Pervious), and Residential – Low Density (Pervious)

The Lake Memphremagog TMDL model included the following loading rate categories applicable to this SOP with individual loading rates for each drainage area (VT DEC, 2017). Loading rates in the Lake Memphremagog TMDL were not broken out by slope as they were in the Lake Champlain TMDL, and only corn was broken out by soil group.

- Continuous corn on clayey soils
- Continuous corn on non-clayey soils
- Continuous hay
- Pasture
- Mixed forest
- Developed pervious
- Developed impervious

Mixed forest, developed pervious, developed pervious, and pasture loading rates are used directly in tracking and accounting methods. Cropland WA is mapped to continuous corn on non-clayey soils.

Limitations of total phosphorus load reduction estimates and accounting methods include:

1. Baseline phosphorus loading rates were the result of watershed modeling and not direct loading measurements at study sites. The model's generalized assumptions may not be applicable to all localized areas.
2. Some phosphorus load reduction efficiencies were not derived from experimental studies conducted in Vermont. Some phosphorus reduction efficiencies were derived from SWAT modeling or studies outside Vermont with different climate and/or agricultural settings. In cases where data were insufficient or conflicting, best professional judgement was also used to establish reduction efficiencies.
3. Realized phosphorus load reductions may differ from estimated phosphorus load reductions due to various factors including climate variability and actual practice performance.

Delivered Load Versus Source Load

Total phosphorus loading rates and targets may be estimated as source load or delivered load. Delivered load is the mass of a pollutant after accounting for estimated pollutant storage or loss enroute to the receiving waterbody. Source load is the pollutant load from the landscape source that does not account for potential storage or loss in the watershed. As water carrying pollutants flows from its landscape source to a receiving water, some pollutants may be attenuated by nutrient uptake in plants, infiltration into soils, or settle out as it flows through inland lakes or ponds before reaching Lake Champlain or Lake Memphremagog. Therefore, the delivered pollutant load is less than at its source (i.e., source load). Delivered load is estimated based on a percent delivery rate that is applied to the source load (summarized in the tables below) and varies and depending on the distance to receiving water and obstacles in its path (e.g., inland lakes). Lake Champlain and Lake Memphremagog phosphorus TMDLs' base load and target load allocations are expressed in delivered load, reflecting total phosphorus load capacity delivered to the lakes. Estimated total phosphorus load reductions are presented as delivered load when reported/presented in the context of TMDLs' base load and target load allocations (e.g., delivered loads are typically reported in the Vermont Clean Water Initiative Annual Performance Report and the Clean Water Interactive Dashboard). However, source loading rates may be used in other applications such as Tactical Basin Planning targets and Water Quality Restoration Formula Grant targets to Clean Water Service Providers (CWSP). Loading rate tables in this document represent source load unless otherwise indicated.

Table 1. The Lake Champlain Phosphorus TMDLs' estimated total phosphorus load delivery percentages by TMDL drainage area

Drainage Area ID	Drainage Area	Champlain Segment	Delivery Percentage
1	Mettawee River	South Lake B	80.4%
2	Poultney River	South Lake B	80.4%
3	South Lake B Direct Drainage	South Lake B	80.4%
4	South Lake A Direct Drainage	South Lake A	98.8%
5	Port Henry Direct Drainage	Port Henry	99.5%
6	Lewis Creek	Otter Creek	63.1%
7	Little Otter Creek	Otter Creek	63.1%
8	Otter Creek	Otter Creek	63.1%
9	Otter Creek Direct Drainage	Otter Creek	63.1%
10	Main Lake Direct Drainage	Main Lake	87.0%
11	Winooski River	Main Lake	87.0%
12	LaPlatte River	Shelburne Bay	79.9%
13	Burlington Bay - CSO	Burlington Bay	96.8%
14	Burlington Bay Direct Drainage	Burlington Bay	96.8%
17	Lamoille River	Malletts Bay	77.6%
18	Malletts Bay Direct Drainage	Malletts Bay	77.6%
19	Northeast Arm Direct Drainage	Northeast Arm	97.4%
20	St. Albans Bay Direct Drainage	St. Albans Bay	90.5%
21	Missisquoi Bay Direct Drainage	Missisquoi Bay	89.9%
22	Missisquoi River	Missisquoi Bay	89.9%
23	Isle La Motte Direct Drainage	Isle La Motte	98.8%

Table 2. The Lake Memphremagog TMDLs' estimated total phosphorus load delivery percentages by HUC 12 watersheds.

HUC 12	Memphremagog Basin HUC 12 name	Delivery Percentage
011100000101	Black River-headwaters to Seaver Branch	91%
011100000102	Black River-Seaver Branch to Lords Creek	100%
011100000103	Lords Creek	98%
011100000104	Black River-Lords Creek to mouth	99%
011100000201	Barton River-headwaters to Roaring Brook	83%

011100000202	Barton River-Roaring Branch to Willoughby River	64%
011100000203	Willoughby River	75%
011100000204	Barton River-Willoughby River to mouth	94%
011100000301	Clyde River-headwaters to Echo Lake stream	34%
011100000302	Seymour and Echo Lakes	11%
011100000303	Clyde River-Echo Lake stream to mouth	60%
011100000501	Direct drainage-south end of Lake Memphremagog	96%

Anticipated Future Improvements

DEC reviews phosphorus accounting methods at least once every five years to confirm the adequacy and accuracy of phosphorus load reduction efficiencies and lifespans. The methods presented below will be updated as new research or information are made available.

DEC understands that some projects such as forest road and trail stream crossing improvement projects may overlap with eligible stream stability credit by restoring connectivity of the watershed. There is potential for projects that divert and infiltrate water from a drainage ditch, form a gully, and enter a perennial stream, to be credited for restoring the temporal connectivity of the watershed. At this time, DEC is not able to apply both forest road reduction credits on top of stream stability measures, as this has not been tested. DEC will work to test these interactions and update accounting methods accordingly.

In addition, the Functioning Floodplains Initiative (FFI) tool is currently only calibrated for use in the Lake Champlain Basin. DEC plans to fund efforts to expand the reach of this tool to Lake Memphremagog. Interim methods to calculate phosphorous reductions within Lake Memphremagog Basin are found in the Stream, Floodplain, and Wetland Restoration section of this document.

Natural Resources Restoration Tracking & Accounting Methods

The following section describes the current tracking and accounting methods for each natural resource restoration project type using the following format:

- Project type definition
- Project type tracking mechanisms
- Determination of area treated

- Baseline loading rate
- Total phosphorus load reduction efficiency
- Design life

Design life is defined in Act 76 as the period of time that a clean water project is designed to operate according to its intended purpose. Phosphorus reductions are initially assigned to a project based on the project's expected design life. However, natural resource restoration projects are designed to help restore the landscape or river to a natural equilibrium stage where nature takes over. The end of a "design life" may trigger an inspection/report for that project, but the benefits of natural resource projects are not expected to have an end date. The **lifespan** and associated pollution reduction credit of any single project may be extended beyond the initial design life if the BMP Verification Program finds the project is still functioning according to its intended purpose. A project's lifespan and associated credit may end when it is no longer functioning, and it cannot or will not be repaired to its original intended purpose. In the natural resource sector, many projects will not have an end of life as the goal is for the benefits to last in perpetuity.

Forested Riparian Buffer Restoration

Forested riparian buffer restoration is the restoration of non-agricultural riparian buffer along rivers and lakeshores. Buffers consist of native woody vegetation (trees and shrubs) with a minimum of 300 stems per acre and a minimum width of 35-feet. Project type cannot be credited with the Native Vegetation BMP or Tree Canopy Expansion BMP from the *Developed Lands Tracking and Accounting SOP* over the same project area.

Forested riparian buffers are credited through three different mechanisms: land use conversion to forest, overland flow treatment, and may be credited for stream stability. Land use conversion and overland flow treatment are discussed in this section, while stream stability is discussed under the Stream, Floodplain, and Wetland Restoration section.

Project Type Tracking Mechanisms

Non-agricultural forested riparian buffers are funded, tracked, and implemented through the following funding programs.

- DEC Clean Water Initiative Program
- Vermont Fish and Wildlife Department
- Lake Champlain Basin Program

Area Treated

The area treated for the land use conversion to forest is defined as the planted buffer area. The area treated for overland flow crediting is defined as five times the buffer area. Using a standard ratio for buffer treatment areas is consistent with the approach used by the Chesapeake Bay Program (CBP 2014).

The 5:1 drainage area ratio for buffers in Vermont was determined using two agricultural buffer treatment area analyses conducted by AAFM and DEC. Although the agricultural buffer analysis may not be perfectly representative of non-agricultural buffers, both buffer types, as funded by the State of Vermont, generally occur on lower-valley streams with low topographical variability, suggesting the agricultural buffer analysis may be transferrable to non-agricultural buffers.

To assess the potential treatment area of agricultural buffers, DEC conducted an analysis using the following steps.

1. Estimate total pasture acres within each HUC 12 in the Lake Champlain basin
2. Estimate the total stream length adjacent to pasture using the National Hydrography Dataset stream layer
3. Estimate the total potential area for buffers by applying a minimum buffer-width (i.e., 35-feet for state or NRCS-funded buffers) to the total stream length adjacent to pasture
4. Calculate the ratio of potential area for buffers to total pasture area. As it was not possible to know if the pasture was bordered on one side by the stream or bisected by the stream, this ratio was calculated assuming both buffers on one side of the stream and buffers on both sides of the streams.

    - Buffer on one side of stream:

    $$\frac{Total\ pasture\ acres - Potential\ buffer\ acres}{Potential\ buffer\ acres}$$

    - Buffers on both sides of stream:

    $$\frac{Total\ pasture\ acres - 2 *\ Potential\ buffer\ acres}{2 *\ Potential\ buffer\ acres}$$

This analysis found a basin-wide average treatment area ratio of 9.66 assuming buffer on one side of the stream and a basin-wide average of 4.33 assuming buffer on both sides of the stream (Figure 2).

AAFM also conducted analysis of the drainage areas around buffers using Conservation Reserve Enhancement Program (CREP) buffer data. For 9 floodplain buffers, the average treatment area was 4.56 acres for each acre of buffer planted, while the average treatment area for 7 upland buffers was 6.30 acres per acre of buffer planted.

Considering AAFM's analysis found a treatment ratio range of 4.56-6.30 for upland and floodplain buffers and DEC's analysis found a treatment ratio range of 4.33-9.66 for one-sided buffers and two-sided buffers, DEC adopted a conservative 5:1 treatment area ratio for agricultural and non-agricultural forested riparian buffers.

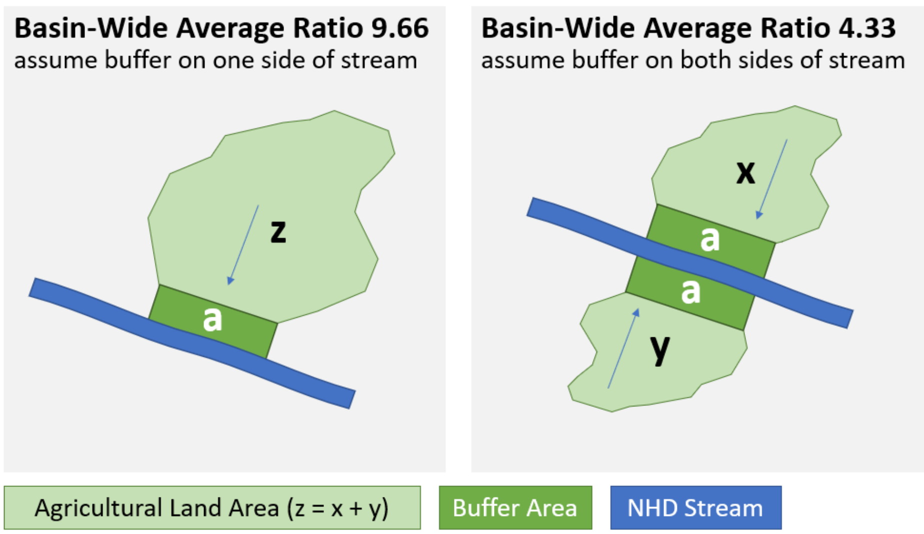

Figure 2. Diagram illustrating the difference in treatment area ratios when assuming buffers are on one side of the stream versus on both sides of the steam.

Baseline Loading Rates

For the land use conversion to forest credit, the baseline loading rate is the land use prior to the buffer planting. In many cases, non-agricultural buffers are planted on open areas of turfgrass, known as the Developed Pervious WA land use.

For the overland flow treatment credit, reporting entities must measure and summarize the land uses in the 5:1 drainage area using satellite imagery, such as Google Maps. The following five upland land use categories are used for simplified reporting.

- Cropland weighted average (WA)
- Pasture
- Forest
- Developed Pervious WA
- Developed Impervious WA

Overland flow credit is not given in areas with impervious surfaces draining to storm sewers. Impervious surfaces like roads and parking lots typically route water into storm sewer systems rather than into riparian areas, so urban buffers are not expected to treat upland runoff and do not receive the extra credit for this function that buffers planted in pervious areas do. The area of impervious surfaces draining to storm sewers in the 5:1 drainage area is subtracted from the total drainage area and not provided phosphorus credit. For example, if a 5-acre drainage area is 4 acres of developed pervious and 1 acre of developed impervious draining to storm sewers, then only the 4 acres of developed pervious receives overland flow credit. Reporting entities are responsible for determining if sewer systems are present within the 5:1 drainage area when reporting land uses to DEC.

Total Phosphorus (TP) Load Reduction Efficiency

Non-agricultural and agricultural forested riparian buffers receive a 40% total phosphorus load reduction efficiency. The Chesapeake Bay Program uses different efficiencies for buffers in different geographic regions of the Bay watershed, ranging from 30 to 50% (Chesapeake Bay Program, 2014). In the literature used to support the TP reduction efficiency by the Chesapeake Bay Program, there was significant variation in the TP reduction efficiencies ranging from 20% to 96% (Simpson and Weammert, 2009).

Vermont and the Chesapeake Bay watershed have similar plains, piedmonts, and mountainous regions (Table 3). The Champlain Valley Region is likely most similar to the poorly drained Outer Coastal Plain subregion considering the relative impermeability of clay and silt soils. Since schist bedrock dominates the Vermont landscape, the Chesapeake Bay Piedmont sub-region comprised of schist and gneiss is likely more similar to Vermont Piedmont than the sandstone-dominated subregion. Similarly, the Valley and Ridge subregion of sandstone and shale bedrock is more comparable to the mountains of Vermont given the similarity between schist and shale. Given that riparian buffer plantings occur across many physiographic regions in Vermont, averaging the corresponding Chesapeake Bay phosphorus load reduction efficiencies would provide a more robust estimate of riparian buffer effectiveness than adopting any single region's efficiency. The average total phosphorus reduction efficiency of the Chesapeake Bay regions most similar to Vermont's biophysical regions was calculated as 39%. 40% was selected as the final efficiency for non-agricultural riparian buffers to be consistent with the efficiency used for agricultural riparian buffers, as described in detail in the separate *Standard Operating Procedures for Tracking & Accounting of Agricultural Conservation Practices*.

Table 3. Comparison of the biophysical regions of Vermont and the Chesapeake Bay watershed.

Vermont Biophysical Region(s)	Comparable Chesapeake Bay Region	Shared Biophysical Characteristics	CBP TP Reduction Efficiency
Champlain Valley	Outer Coastal Plain (Poorly Drained)	Poorly drained, often saturated soils; low elevations; dominated by	39%

		wetland ecosystems	
Vermont Piedmont	Piedmont (schist and gneiss)	Schist bedrock, seepage wetlands, rolling hills of moderate elevations	36%
Green and Northeastern Mountains	Appalachian Plateau Valley and Ridge (Sandstone and Shale)	Plateau structure; calcium-rich soils; acidic bedrock; relatively high elevations	42% 39%

Design Life

The design life for forested riparian buffers is 20 years with potential for credit to be extended based on successful verification. A Pennsylvania survey indicated that 80-85% of landowners will not alter the riparian buffer once established, and a review of riparian buffer effectiveness in the Chesapeake Bay watershed suggests that the lifespan of riparian buffers may be close to 40-120 years (Chesapeake Bay Program, 2014). A more conservative estimate of the upper lifespan of riparian forest buffers is 30 to 40 years although buffers must be properly maintained over their lifespan (Simpson and Weammert, 2009). DEC has added additional conservativeness to the design life to account for unforeseen circumstances, such as transfer of land ownership or accidental mowing.

Riparian Buffer Tracking & Accounting Summary

Table 4. Summary of data used for estimating phosphorus reductions from forested riparian buffer restoration.

Data Required	Source
Baseline phosphorus loading rate • Latitude and longitude start and end points of planted area • Land use of buffer area prior to planting • Acres of each land use in drainage area (5x buffer acres) and planting area	Lake Champlain TMDL model (Tetra Tech, 2015a) Lake Memphremagog TMDL model (VT DEC, 2017)
Buffer acres	Reporting entity
Practice efficiency	40% plus land use conversion to forest
Practice Design Life	20 years

Bioengineered Shoreline Stabilization

Bioengineered shoreline stabilization is the implementation of lake shoreline stabilization practices using a combination of biodegradable materials and native plantings to naturally stabilize slopes. Restoration techniques include, but are not limited to, encapsulated soil lifts, slope regrading, and crib walls. See the *Vermont Bioengineering Manual* to learn more about how to minimize shoreline erosion and design solutions for stabilizing weakened and eroding banks. For other shoreland practices, upland of the lake shoreline, such as green stormwater infrastructure, native revegetation, and tree canopy expansion, see the separate *Developed Lands Tracking and Accounting SOP*.

Phosphorus loading and reductions from lake shorelines were not modeled in the Lake Champlain or Lake Memphremagog TMDLs. As a result, phosphorus credits for shoreline stabilization projects are credited to allocations based on the adjacent land use. For example, if a shoreline restoration project is directly adjacent to developed pervious (e.g., lawns) or impervious (e.g., roads) land uses, the credit will be given to the developed lands load allocation. Shoreline restoration directly adjacent for forested and agricultural land uses will be credit to the forest and agricultural load allocations, respectively. Adjacent land uses will be determined visually in the field by reporting entities.

Project Type Tracking Mechanisms

Bioengineered shoreline stabilization projects are funded, tracked, and/or implemented through the following programs.

- DEC Clean Water Initiative Program
- DEC Lake Wise Program

Baseline Loading Rates

The baseline condition is defined as the volume of erosion prior to remediation, following the approach used by Chesapeake Bay Program (2019).

$$\begin{aligned}&Volume\ of\ sediment\ erosion\ (ft^3)\\ &\quad = Length\ of\ Shoreline\ (feet) * Average\ Bank\ Height\ (feet)\\ &\quad * Average\ Shoreline\ Recession\ Rate\ \left(\frac{feet}{year}\right)\end{aligned}$$

Generally, there are four causes of shoreline sediment erosion: wind, wave, ice, and upland stormwater runoff. Human activities along the shore often exasperate natural causes intensifying their erosive affects. Erosion along lakeshores can occur gradually when individual soil particles wear away or quickly when large, sloped areas become unstable and slough into the lake.

Recession rates refer to inches of fastland erosion (i.e., erosion above the water line). To estimate the shoreline recession rate, the landowner should be consulted about how much the shoreline has receded in the past 10 years. If possible, landowner photos or areal imagery of shoreline recession over the past 10 years should be reviewed to estimate the rate. If the landowner or engineer have direct measurements of shoreline recession rates, those more accurate data may be used instead of the simplified categories. If there are shoreline restoration projects outside of the 0-6 inches/year of erosion range described below, partners must contact the Clean Water Initiative Program and Lakes and Ponds Program to discuss the appropriate erosion rate to use for the project. Shoreline recession rates for scouring banks are grouped into the following three categories for simplified reporting.

- **Low erosion: 0-2 inches/year.** The most common type of shoreland erosion occurs slowly over time, causing less than two inches of soil erosion per year or even pausing for a period of time until continuing to erode again under severe storms.

Figure 3. Examples of low shoreline erosion rates estimated at 0-2 inches per year.

- **Moderate erosion: 2-4 inches/year.** Vegetative banks buffer shorelines from wind, wave, and ice energy while binding the soils together also protecting the bank from erosive upland runoff. When the vegetation is removed, erosion can occur in many forms, including scouring underneath which ultimately undermines and weakens the entire bank.

Figure 4. Examples of moderate shoreline erosion rates estimated at 2-4 inches per year.

- **Severe erosion: 4-6 inches/year.** Shorelands with more than a 20 percent slope (one foot vertical to five feet horizontal) are considered steep shores with increased erosion potential. Plants typically root best on slopes less than 30 percent but can grow on slopes up to 50 percent. Nonetheless, when shores become unstable on steep slopes, severe erosion will occur. Another type of severe erosion occurs on man-made beaches made of sand. Sand is very unstable and will severely erode annually, washing into the lake and disturbing natural aquatic habitats.

Figure 5. Examples of severe shoreline erosion rates estimated at 4-6 inches per year.

Volume of sediment erosion (ft^3) is converted to kilograms of phosphorus using sediment bulk density and sediment phosphorus concentration values. At the time of writing, there were no local research papers measuring sediment bulk density and sediment phosphorus concentrations within Vermont's inland lake shorelines. As a result, several local research papers on streambank sediments were reviewed instead to approximate conversions lake shoreline projects. It should be noted, however, that streambanks and lake shorelines may have different sediment bulk density values based on sediment texture, time since deposition, and hydrologic condition. Sediment phosphorus content may also differ between stream and lake environments as sediment phosphorus concentrations are correlated with oxidized metals and organic matter abundance which varies from stream to lake environments. These conversions may be updated over time as localized data on lake shorelines are made available.

Several streambank studies in Vermont have measured sediment bulk density and total phosphorus concentrations ([TP]). Ishee et al. (2015) reported a weighted mean sediment bulk density value of 1.20 Mg m^{-3} (34.0 kg/ft^3) for streambank soils in Chittenden County, while Ross et al. (2019) reported a range between 1.20 and 1.40 Mg/m^{-3} (34.0-39.7 kg/ft^3) for streambanks in the Mad River watershed. To be conservative in the conversion, a sediment bulk density value of 34.0 kg/ft^3 is used in this accounting method.

For sediment phosphorus content, Ishee et al. (2015) reported an overall mean of 621 mg/kg. DeWolfe et al. (2004) reported an average of 613 mg/kg, which was similar to the 600 mg/kg national average for total phosphorus in soils reported in Abrams and Jarrell (1995). Young et al. (2012) reported a higher average of 678 mg/kg, but this higher value along with other measured characteristics suggests historic land use and possibly legacy phosphorus at their study sites. Similarly, Ross et al. (2019) reported range of 728-994 mg/kg but suggest that the elevated values are likely due to phosphorus amendments associated with agricultural uses at 5 of their 6 sites. To be conservative in the conversion, the 621 mg/kg (0.000621 kg TP/kg sediment) value from Ishee et al. (2015) is used in this accounting method. After applying the sediment bulk density and total phosphorus conversions, the baseline units are kg of total phosphorus per year (kg TP/year). Altogether, cubic feet of sediment erosion (ft^3/year) can be multiplied by 0.02 kg TP/ft^3 to obtain kilograms of total phosphorus erosion per year.

Total Phosphorus Load Reduction Efficiency

The Chesapeake Bay Program provides a 100% efficiency for shoreline stabilization projects because the erosion equation above only accounts for fastland sediment, but shoreline stabilization projects prevent both fastland and nearshore erosion. Fastland erosion is erosion of land that lies above the waterline, and nearshore erosion is erosion of sediments in the shallow region just below the waterline. As a result, this accounting method should theoretically provide a conservative estimate of the phosphorus prevented from eroding. This efficiency, however, is later lowered by 33% (Virginia) or 55% (Maryland) depending on the percentage of sand in the shoreline because sand is not a detriment to Chesapeake Bay water quality. There is also additional flexibility for local or state agencies to give partial or no credit for shoreline stabilization sites that are at continued risk of erosion (e.g., storm and wave events impact the base of the bank).

DEC believes, however, that the sediment bulk density and phosphorus content conversions used above appropriately consider the contribution of sand to shoreline phosphorus in Vermont. DEC also believes that there does not need to be additional conservativeness in the efficiency for sites at continued risk of erosion since Vermont's inland lakes are subject to less erosive forces than the tidal Chesapeake Bay. Rather than adopting the Chesapeake Bay's original 100% efficiency, DEC is adopting a conservative 85% total phosphorus load reduction for shoreline stabilization projects in Vermont because DEC believes that no project is 100% effective at reducing phosphorus loading to surface waters.

Design Life

Chesapeake Bay Program gives a five-year lifespan which may be extended if the efficacy of the site merits extension. The shorelines within the Chesapeake Bay, however, are exposed to greater hydrodynamic forces (e.g., tides, waves) than the shorelines of inland lakes within Vermont, suggesting a 5-year design life may be an overly conservative estimate. Considering this and the best professional judgement of the DEC Lakes Program, the initial design life of bioengineered stabilization projects in Vermont is 10 years, but the lifespan and associated credit may be extended upon verification.

Shoreline Stabilization Tracking & Accounting Summary

Table 5. Summary of data used for estimating phosphorus reductions from bioengineered shoreline stabilization projects.

Data Required	Source
Baseline phosphorus loading rate • Latitude and longitude • Volume of erosion before restoration (length x average height x shoreline recession rate) • Sediment bulk density (34.0 kg/ft^3) • Sediment phosphorus content (0.000621 kg TP/kg sediment)	Erosion measured by reporting entity Conversions from Ishee et al. (2015)
Practice efficiency	85%
Practice lifespan	10 years

Forest Road & Trail Erosion Control

Forest road and trail erosion control is the implementation of forest logging road, trail, and/or stream crossing best management practices (BMPs) to address erosion to control nutrient and sediment pollution from forested lands or legacy erosion from historic forestry operations.

BMPs are consistent with *Acceptable Management Practices (AMPs) for Maintaining Water Quality on Logging Jobs in Vermont* standards.

Project Type Tracking Mechanisms

The AMPs are intended and designed to prevent sediment, petroleum products, and woody debris (logging slash) from entering Vermont's waters.[2] The Vermont Department of Forest, Parks, and Recreation (FPR) has developed a Road Erosion Inventory (REI) using Survey123 for Agency of Natural Resources (ANR)-owned forest truck roads that assesses road segment compliance with AMP standards. The REI is modeled after the Municipal Roads General Permit REI assessment and scoring system, as described in the *Developed Lands Tracking & Accounting SOP*. This REI approach may be applied to other priority forest road networks to inform project prioritization, implementation, and tracking and accounting in the future.

In order to track forest road projects, roads were divided into 100-meter road segments with unique identification numbers using a geographic information system (GIS) analysis. Forest road segments are classified as either hydrologically connected or non-hydrologically connected. All ANR-owned hydrologically connected segments are being assessed for compliance with AMP standards. Segment analysis allows ANR to prioritize and pursue projects to address erosion risk and to protect water quality on its forest road system. Hydrologically connected forest road segments are defined as the following:

- Forest roads within 100' to a water of the state or wetland;
- Forest roads that bisect a water of the state or wetland or a defined channel;
- Forest road segment is uphill from, and drains to, a forest road that bisects a water of the state or wetland, or defined channel.

The degree to which each road segment adheres to the AMP standards, as determined through questions in the REI app, determines its compliance score. Compliance scores fall in to three categories: Does Not Meet (DNM), Partially Meets (PM), or Fully Meets (FM) standards. BMPs increase compliance scores and change in compliance scores is the basis for the forest road erosion control accounting methodology.

Area Treated

The area treated for each forest road erosion remediation project is defined as the 100-meter road segment of the project.

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[2] AMPs can be accessed here: https://fpr.vermont.gov/forest/managing-your-woodlands/acceptable-management-practices

Baseline Loading Rates

The baseline phosphorus loading rate for forest areas in the Lake Champlain TMDL assumes that the primary sources of sediment and phosphorus export within the forest land sector are forest roads and skid trails. Based on Gucinsky et al. (2001), it was assumed that 4.5% of the total forest area is made up of some type of forest road or skid trail, and the Wemple (2013) unpaved road loading rates were used in the Lake Champlain TMDL to estimate road loading for a given area. No additional loading was calculated for harvest areas beyond the total forest road and skid trail load. The Lake Champlain TMDL SWAT model provided estimates of the total load from the forest sector in each lake segment watershed but was not able to partition this total load into the sub-categories of forest roads (primarily truck roads, skid trails, and log landings). Due to the lack of specificity in forest road loading rates and the potential overestimation of loading rates due to using unpaved roads data, DEC contracted with Watershed Consulting Associates to develop more specific and accurate forest road loading rates for phosphorus accounting.

Following the guidelines for soil erosion model selection outlined in Fu et al. (2010), a variety of empirical and physical models were reviewed for application in this methodology. Empirical soil erosion models are based on statistical relationships between responses and independent variables, derived from empirical observations. Conversely, physical models are based on a hydrological response model that simulates infiltration and runoff routing and mass or energy conservation equations that describe erosion and sediment delivery processes (Merritt et al., 2003). Widely known and utilized empirical models include Universal Soil Loss Equation (USLE; Wischmeier and Smith, 1965), USLE-derived models (USLE-Forest; Dissmeyer and Foster, 1984), and the Revised USLE (RUSLE; Renard, 1997). Physical models that are well known and regularly utilized were evaluated including the Water Erosion Prediction Project (WEPP; Flannagan and Nearing, 1995) and WEPP-derived models (WEPP:Road; Elliot, 2004). For this application, WEPP:Road was determined be the most appropriate due to the model's spatio-temporal suitability, ease of use, manageable data requirements, simple web-based interface, and ability to assess multiple road segments simultaneously via a batch import function.

The WEPP:Road model is a physical-based program that calculates erosion and sediment yield, primarily from roads, though it can be used to determine sediment yield from other practices as well as log landings. It was originally developed in 1995 by the USDA Agricultural Research Services to be used by federal action agencies in environmental planning and assessment (Flannagan and Nearing, 1995). The fundamental mechanics of the model describe a process by which the sediment produced from a road segment is routed over a fillslope and across a forest buffer before reaching nearby surface waters. The WEPP:Road model is particularly well suited for conditions common to forest management practices as it utilizes equations to describe the following processes:

- Infiltration and runoff,
- Soil detachment, transport, and deposition, and
- Plant growth, death, and residue decomposition.

To generalize the WEPP:Road model for the purposes of this methodology, 28,801 model runs were conducted using a variety of unique combinations of input variables to represent truck road conditions and 15,363 model runs using variables that represent skid trail conditions. The result of the model runs were more specific sediment and phosphorus production estimates for forest road and trail tracking and accounting that vary based on climate station, soil conditions, road design, road surface, traffic level, road gradient, buffer gradient, and buffer length. The initial sediment and phosphorus production load is then multiplied by an estimate of the percentage of sediment and phosphorus reaching a waterbody, as determined by the forest buffer length and forest buffer gradient, to account for the road segment's hydrologic connectivity.

To validate this methodology, the phosphorus loading rates derived in this methodology were compared to those in the Lake Champlain TMDL. The Lake Champlain TMDL model assumed that forest loading rates were 5.6 kg/ha/year, which was an unpaved road loading rate from Wemple (2013). The average of the statewide WEPP:Road truck road loading rates to streams was 4.63 kg P/ha/year (Table 6). While this average loading rate is lower than the Wemple (2013) loading rate for unpaved roads, DEC believes that the forest road loading rate to streams should be lower than the loading rate for unpaved roads.

For a full description of the method used to develop forestland loading rates, as well as the final loading rates and connectivity factors used in crediting, see Appendix A. Note that loading rate variables used in Appendix A may be further consolidated to align with REI data collection procedures.

Table 6. Average phosphorus production rates and average phosphorus loading rates to streams (i.e., accounting for hydrologic connectivity) from forest roads and skid trails.

	Phosphorus Leaving the Road (kg P/ha/year)	Phosphorus Reaching Streams (kg P/ha/year)
Truck Roads	8.05	4.63
Skid Trails	6.16	3.26
Overall (assuming 80% skid trails, 20% truck roads)	6.53	3.53

Total Phosphorus Load Reduction Efficiency

AMP standards for forest roads are based on the implementation of a suite of erosion control practices. Rather than accounting for phosphorus load reductions for each individual forest road BMP installed, phosphorus load reductions are accounted for at the road segment-level based on compliance with AMP standards in the REI. The initial REI assessments serve as the baseline condition from which phosphorus reductions are estimated. Road projects that improve the compliance score for a segment (e.g., *Does Not Meet* to *Fully Meets*) will receive phosphorus load reductions.

Phosphorus reduction efficiencies for changes in AMP compliance were adapted from the efficiencies used for MRGP compliance, which were developed based on Wemple and Ross (2015). Wemple and Ross (2015) measured sediment reductions associated with individual municipal road BMPs rather than reductions resulting from a suite of practices based on MRGP compliance; therefore, DEC stormwater specialists formed a workgroup to develop MRGP compliance phosphorus reduction efficiencies informed by Wemple and Ross (2015). As shown in Table 6, projects that result in the compliance status changing from *Does Not Meet* to *Fully Meets* receive an 80% phosphorus load reduction efficiency. For projects that result in the compliance status changing from *Does Not Meet* to *Partially Meets* or from *Partially Meets* to *Fully Meets*, a 40% phosphorus load reduction (half credit) is provided. These percent reductions are applied to the baseline forest road loading rate for the segment, as described above.

Table 7. Total phosphorus load reduction efficiencies based on change in AMP compliance status.

To \ From		Pre-Construction Compliance Status	
		Partially Meets	*Does Not Meet*
Post Construction Compliance Status	*Partially Meets*	0%	40%
	Fully Meets	40%	80%

* Percent reductions are calculated relative to the loading rate for segments not meeting standards

It is important to note that the efficiencies developed for municipal road erosion remediation may not be fully representative of benefits of AMP implementation. However, controlled watershed studies in forested watersheds that measured the effectiveness of BMPs on phosphorus reduction have found that a comprehensive application of forest management BMPs in harvest areas has resulted in an 85 – 86% reduction of phosphorus loads (Edwards and Williard, 2010). A number of studies have also measured the effectiveness of individual forest road BMPs, and many of these BMPs were found to achieve similar reduction efficiencies to the harvest area BMPs. While most of these studies evaluated sediment reductions rather than nutrients, studies that have assessed the effectiveness of both sediment and phosphorus have found a high correlation between the two (Wynn et al., 2001; Arthur et al., 1998). A synthesis compiled by Edwards et al. (2015) indicated that Witt et al. (2011) found an 84% efficiency for portable bridges and a 77% efficiency for temporary culverts. The efficiencies of forest buffers between forest roads and waterbodies have not been well studied, but Packer (1967) calculated that forest buffers from 9 to 46 meters could retain 85% of sediment flows from cross drains. Damian (2003) found broad-based dips at approaches to water crossings to be 50% effective in modeling studies. The combined efficiencies would be higher than the individual BMP efficiencies, so an overall efficiency of 85% (consistent with Edwards and Williard, 2010) was used in the TMDL analysis for forest roads (Tetra Tech 2015a). This 85% value is approximate to the 80% credit given for the greatest increase in forest road AMP compliance (i.e., *Does Not Mee*t to *Fully Meets*), providing support for these efficiencies.

Design Life

Different design lives are used for truck roads and skid trails. **Truck roads** are forest roads that connect a log landing to a public road system, and they may be designed, constructed, and maintained to provide either permanent or temporary access. **Skid trails** are cleared trails that are used by logging equipment during a logging operation to transport harvested trees and logs to a log landing. Generally, truck roads get more incidental use than skid trails and skid trails may revegetate to natural conditions. As a result, the design life for projects on truck roads is 5 years and 10 years for skid trails.

The design life for AMP compliance lasts 5 years for truck roads and 10 years for skid trails. If the segment is still in compliance At the time of an REI assessment,, the lifespan and associated credit will be extended. If the project is not in compliance, the credit is ceased until the segment is brought back up to standards.

Forest Road Erosion Control Tracking & Accounting Summary

Table 8. Summary of data used for estimating phosphorus reductions from forest road erosion control projects.

Data Required	Source
Baseline phosphorus loading rate • County • Runoff potential (traffic level, road design) • Road segment slope • Soil type • Road type (truck road or skid trail)	Loading rates provided in Appendix A

Data Required	Source
• Forest buffer gradient • Distance from waterbody • Compliance scores pre-restoration	
Practice efficiency	40-80% depending on increase in compliance score and road type
Design life	5 years for truck roads, 10 years for skid trails

Use Value Appraisal Enrollment

Vermont's Use Value Appraisal (UVA) Program enables eligible private landowners who practice long-term forestry to have their land appraised based on the property's value of production of wood rather than its residential or commercial development value. To qualify, parcels must contain at least 25 acres that will be enrolled and be managed according to a forest management plan approved by the Vermont Department of Forests, Parks and Recreation (FPR). Parcels enrolled in the UVA Program require application of the *Acceptable Management Practices (AMPs) for Maintaining Water Quality on Logging Jobs in Vermont* to the maximum practical extent possible.

Forestland parcels enrolled in the UVA Program are eligible for phosphorus credit if the 10-year forest management plan and compliance work began after the TMDL modeling periods. For the Lake Champlain basin, this refers to UVA enrollment only after 2010. For the Lake Memphremagog basin, this refers to UVA enrollment only after 2012. Note that the UVA program also enrolls agricultural parcels, but agricultural parcels are not credited under this accounting methodology. Forest lands cannot receive credit for both UVA Enrollment and Forest Road Erosion Control without review and approval of the Clean Water Initiative Program and FPR to avoid duplication of credit.

Project Type Tracking Mechanisms

FPR tracks parcels enrolled in the UVA Program in the Current Use Management Plan Tool database. The database tracks the parcel School Property Account Number (SPAN number) for identification, enrolled acres, forest management plan development year, and last inspection year.[3] Presence of a parcel in the database indicates current UVA enrollment, except for a few

[3] Years represent "enrollment years" beginning April 1. For example, enrollment year 2021 is April 1, 2021 to March 31, 2022.

cases where compliance issues are currently being resolved. Non-compliant parcels are removed from the database if the issues are not resolved in a timely manner.

Area Treated

The area treated is defined as the acres of forestland enrolled in the UVA Program.

Baseline Loading Rates

The Forest WA loading rates adapted from the Lake Champlain and Lake Memphremagog TMDL models are used to determine the baseline loading rate for UVA parcels.

Total Phosphorus Load Reduction Efficiency

The total phosphorus load reduction efficiency for UVA compliance is based on a BMP implementation and maintenance audit developed by the Virginia Department of Forestry (Lakel, 2014). The audit contains 84 questions regarding the implementation of BMPs across various categories, including harvest planning, truck roads, skid trails, stream crossings, forest buffers, and wetlands. Audit scores are reported as the percentage of applicable audit questions that received an answer of "Yes" on the audit. The score determines the sediment and phosphorus reduction creditable for the implementation of the suite of BMPs. Audit scores less than 80% refer to "low forestry BMP utilization, scores of 80-90% refer to "standard for "Forestry BMP utilization", and scores above 90% are "high forestry BMP utilization", as shown in the table below.

The low, standard, and high BMP utilization were credited with 0%, 40%, and 80%, respectively. The total phosphorous (TP) reduction efficiency values representing each level of proper BMP utilization and implementation are conservative estimates based on existing United States Department of Agriculture (USDA) Forest Service reports and published erosion and sediment research summarized in Cristan et al., (2019) and Nolan et al., (2015). In comparing published data, Cristan et al., (2019) determined that standard BMP implementation reduced estimated sediment load by 75% compared to low BMP implementation levels. High levels of BMP implementation were estimated to potentially remove nearly all forest operation produced sediment. This study does note, however, that the reduction estimates were based on limited data and address only one year following harvest.

Table 9. Sediment and phosphorus efficiencies based on BMP compliance status.

BMP Utilization Levels	Audit Score	TP Reduction Efficiency
Low	< 80%	0%
Standard	80 – 90%	40%

High	90 – 100%	80%

The 40% and 80% efficiencies are in the range of efficiencies recommended elsewhere for forest roads. The Chesapeake Bay Program (CBP) also evaluates forestland BMP effectiveness within a full set of BMPs employed in a watershed and not for any individual practice. Currently, the Chesapeake Bay Program uses a conservative reduction efficiency for sediment and phosphorus of 60% (Simpson & Weammert, 2009), which is within the 40-80% efficiency range for Vermont. The paired-watershed studies on which CBP recommendations are grounded are summarized in the table below. The Lake Champlain TMDL also recommended an 85% efficiency for forestland BMPs based on a literature review, as described above (Tetra Tech 2015a).

Table 10. Efficiencies forestry BMPs as determined from various studies.

Reference	Time Period	Calculated Efficiency	
		Sediment	TP
Kochenderfer and Hornbeck (1999)	1st yr after harvest	96%	N/A
	2nd yr after harvest	76%	
Wynn et al. (2000)	Post- harvest	94%	86%
	Post site-prep	91%	85%
Arthur et al. (1998)	During Harvest	53%	N/A
	1st yr after harvest	34%	44%
	2nd yr after harvest	2%	N/A
	4th yr after harvest	53%	N/A
	5th yr after harvest	94%	N/A
	6th yr after harvest	78%	N/A

To determine the single efficiency to use for all UVA parcels, FPR conducted a crosswalk between UVA requirements and the 84 audit questions. Of the 78 questions applicable to UVA parcels (i.e., different geographies or program requirements), UVA requirements scored an 87% on the overall audit, which relates to a 40% efficiency. However, UVA program requirements satisfy all of the questions specifically related to a discharge of sediment and phosphorus. Furthermore, there are additional water quality requirements in the UVA program that are not captured in the Virginia audit questions. As a result, FPR believes an 80% efficiency is justified for UVA parcels. The complete list of audit questions and results of the crosswalk with UVA program requirements are listed in Appendix B.

Design Life

Phosphorus crediting for parcels enrolled in the UVA program begins July 1 of the enrollment year reporting. The design life is 10 years unless an inspection deems the parcel non-compliant. Non-complaint parcels must remediate issues under the upcoming period of dry soil conditions, or they are removed from the database and credit is ceased if the issues are not resolved in a timely manner.

Use Value Appraisal Enrollment Tracking & Accounting Summary

Table 11. Summary of data used for estimating phosphorus reductions from UVA enrollment.

Data Required	Source
Baseline phosphorus loading rate • Parcel location (SPAN number; related to TMDL drainage area) • Enrolled acres	Current Use Management Tool Database
Practice efficiency	80%
Practice Design Life	10 years

Stream, Floodplain, and Wetland Restoration

Stream, floodplain, and wetland restoration phosphorus accounting methods were established by the Vermont Functioning Floodplains Initiative (FFI).[4] The goal of FFI is to provide practitioners, program managers, and policymakers with the maps and data they need to protect and restore highly valued streams, wetlands, riparian areas, and floodplains in the Lake Champlain Basin of Vermont. To support the implementation of the Lake Champlain TMDL, the FFI team developed the following phosphorous accounting method for stream, floodplain, and wetland restoration projects that estimates the phosphorus reduction associated with bringing an entire stream reach and HUC 12 watershed to a more connected and stable geomorphic condition (Schiff et al., 2021a).

Restoration efforts credited under this approach include floodplain and channel reconnection, dam removal, berm removal, restoring channel roughness, removing hard constraints, river corridor easements, adopting river corridor bylaw, conserving wetlands, buffer establishment,

[4] More information on the Functioning Floodplain Initiative can be found here: https://dec.vermont.gov/rivers/ffi

replacing bridges and culverts, and minimizing water diversions. Credit can also be given for changes in connectivity scores identified through stream geomorphic assessments.

Connectivity departure refers to breaks in the continuum of flow between upstream and downstream and between the stream and its floodplain that result in an imbalance in the natural processes that moderate sediment and nutrient loading at the watershed scale. **Vertical connectivity** is a measure of a stream's access to its floodplain at bankfull flows (~Q1.5) and represented by the incision ratio (IR), which is a measure of bed degradation or downcutting. The **lateral connectivity** is characterized by the available space in the river corridor that is free of physical constraints to river movement; land protections such as river corridor easements; and natural riparian vegetation. **Longitudinal connectivity** is the upstream/downstream connection across the stream network and is important for the downstream movement of water, sediment, large wood, coarse particulate organic matter, nutrients, and ice; for the upstream and downstream movement of fish, aquatic organisms, and wildlife. **Temporal connectivity** is the resulting timing of flood flows accessing floodplains based on watershed hydrology and the flow characteristics within the stream network as measured by the magnitude, frequency, and duration of flows.

At a high level, the following information is needed to estimate phosphorus reductions from stream, floodplain, and wetland restoration projects in the Lake Champlain basin.

- **Baseline stream stability phosphorus loading rate for stream segment**. Data requirements include segment location (headwaters or lower valley), segment connectivity departure scores before project implementation, and river corridor acres.
- **Segment connectivity departure scores after project implementation or stream geomorphic assessment.** Improvements in connectivity departure scores after project implementation or stream geomorphic assessment increase stream equilibrium and therefore reduce net phosphorus loading to Lake Champlain. Projects can receive credit through two different mechanisms – stream stability and floodplain storage – and project credits vary over time by project type.

The complete methods and rationale for estimating phosphorus reductions from stream, floodplain, and wetland restoration projects are described below and within appendices. Please note that the FFI accounting methods were established specifically for the Lake Champlain basin. An interim phosphorus crediting method for the Lake Memphremagog basin was established using median P load reduction credits by project type from Lake Champlain basin data, as described below. DEC plans to fund an FFI project specifically for the Lake Memphremagog basin in the future.

Project Type Tracking Mechanisms

Stream, floodplain, and wetland restoration projects are funded through both regulatory and non-regulatory mechanisms. Municipal Separate Storm Sewer System (MS4) communities may occasionally implement floodplain restoration projects to help meet Phosphorus Control Plan (PCP) requirements, but most restoration projects are funded through the following non-regulatory funding programs.

- DEC Clean Water Initiative Program
- Vermont Fish and Wildlife Department
- Lake Champlain Basin Program

The FFI team, including DEC staff and hired consultants, is developing a web-based system for planning and tracking implementation, effectiveness, and value of river and floodplain/wetland restoration and conservation projects. This system will allow users to readily access information and visualize maps developed in prior efforts and will be designed to track implementation of projects to understand how progress is being made at different scales towards restoring stream equilibrium, floodplain functionality and flood resilience. The tracking interface will be used to update and display implemented projects at the parcel, reach, HUC12 sub-watershed, and basin scales, and provide updated calculations of benefits. The tool is expected to be completed in 2022. For more information on how the FFI tool will interact with the Watershed Projects Database, please see Appendix H.

Basis for Phosphorus Crediting

Under the Lake Champlain TMDL, the baseline total phosphorus (TP) load attributed to stream instability has been allocated to TMDL sub-basins – one or more sub-basins make up each HUC 12 watershed in the Lake Champlain Basin (Figure 5 and Appendix C. Lake Champlain TMDL Stream Sector Assumptions). TP base load allocations at the sub-basin level are needed for TMDL tracking and accounting of TP load reductions resulting from resource management and projects implemented at the geomorphic reach, segment, or sub-unit scale. Allocating TP base loads to river channels at a sub-basin scale recognizes that stream processes, channel evolution trajectories, and stream stability largely operate over geomorphic stream reaches at the watershed scale rather than at individual sites.

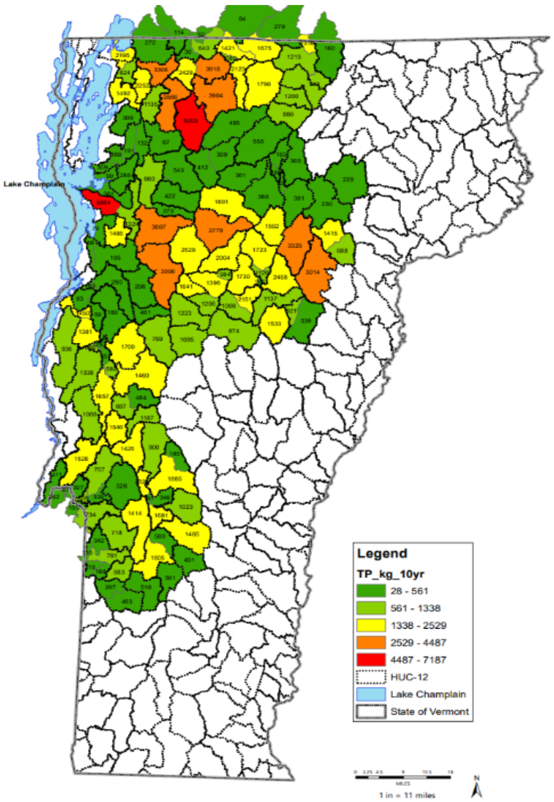

Figure 6. Lake Champlain sub-basin phosphorus load allocations.

Stream stability practices are not a conventional BMP in the TMDL context. 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 TP reduction associated with bringing an entire stream reach and HUC 12 watershed 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 (Tetra Tech, 2015a, b).

Floodplain (vertical and lateral) and stream (longitudinal and temporal) connectivity (or the lack thereof) are a reflection of ongoing channel evolution processes and stream dynamic equilibrium. Structures, channelization, and land use practices in the river corridor or floodplain have and will continue to result in disconnectivity, creating an unnatural imbalance between erosion and deposition processes. This imbalance in stream networks leads to a loss of ecosystem services and habitat, including reduced inundation-related storage processes (e.g., floodplain storage) in natural wetland and floodplain features, increased flood vulnerability, stream channel instability, and degraded riparian habitat.

To restore and protect stream and floodplain connectivity, a project and channel evolution crediting system has been developed, facilitated by downscaling of the TMDL sub-basin TP base load allocation to the geomorphic subunit, segment, or reach scale (Schiff et al., 2021b). The TP allocation and crediting system described below, recognizes that projects implemented to improve stream and floodplain connectivity will affect stream processes and nutrient loading occurring at both site and sub-basin scales and may therefore be awarded multiple TP load reduction credits depending on erosion-reduction, deposition, and inundation processes affected by the project.

TP load reduction credits are achieved through two key mechanisms: 1) improving stream stability; and 2) enhancing floodplain storage (Figure 7). Stream stability and storage may be restored through the removal of constraints and protection of the natural processes that work toward equilibrium conditions and/or through the physical removal of legacy sediments that overburden historic floodplains and contribute to channel incision. A given restoration project may include one or more of these components. This connectivity-based framework for TP base load allocation and crediting is predicated on the understanding that restoring connectivity will increase stream equilibrium and therefore reduce net P loading to Lake Champlain. Ongoing river and floodplain research is revealing a gradient of connected settings that each influence P storage and retention. As research products become available, they will be integrated to further inform project priorities and crediting.

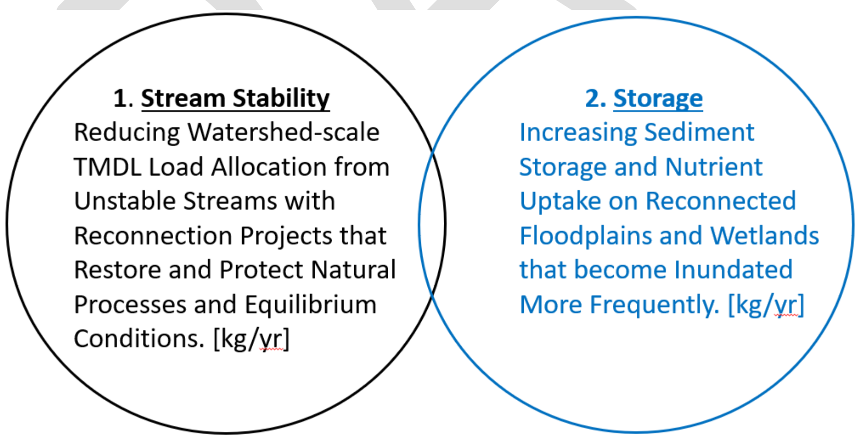

Figure 7. Two methods for achieving P load reduction credit with projects to restore and protect floodplain and stream connectivity.

The FFI stream stability allocation and crediting system recognizes the relative contribution of different types of connectivity departure at the watershed scale and credits projects for contributing to the restoration and protection of stream processes that affect both reach-scale stability and equilibrium beyond the project site to the watershed as a whole. As watershed-scale stability increases and the HUC 12 TP base load decreases, a lower allocation is redistributed down to the reach scale. This means an individual project completed later in time would be reducing a lower remaining base load, and therefore be awarded a lower TP credit.[5] To keep the initial award of project credits static (i.e., with no reallocation of a smaller base load) would imply that all the benefits of a project are accrued at the project site at one time (i.e., erosion/deposition are only influenced by connectivity within the reach as affected by in-reach projects). Base loads and credits get lower as equilibrium in the watershed is achieved because stream processes operate to affect equilibrium at larger scales. In other words, as the base load allocation value decreases due to completed projects and ongoing management that facilitates passive restoration, the FFI will automatically shift the remaining nutrient load within the HUC 12 to reaches with the greatest remaining connectivity departure. If a watershed were to become near fully connected and protected at or near equilibrium conditions, it would be less cost effective to intervene with restoration projects there, compared with doing projects in another watershed where greater systemic instability remains.

Baseline Loading Rates

Stream stability base loads are allocated in following three major steps.

1. The first step involves **splitting the base load between headwaters and lower valley** reaches within each HUC 12.
2. The second step **allocates the base load among stream subunits using connectivity scoring** considering their relative contribution to the departure or imbalance of the stream-floodplain processes that drive sediment and nutrient loading at the watershed scale. This allocation creates an awareness and rewards for restoring and protecting all types of connectivity in the watershed in order to achieve the overall desired base load reduction. It discourages further disconnections that may occur were there no categorical allocation (i.e., nothing to lose), and allocations were only made to the current sources of loading. It promotes active restoration and conservation projects, as well as natural resource management programs that prevent backsliding. For instance, technical and regulatory assistance programs and educational programs successfully

[5] These are the initial credits that, once awarded with the completion of the project, would remain unchanged over time. To illustrate this, if the HUC 12 base load recorded in the FFI starts out at 500 lbs/year and then a buffer project in that watershed is awarded a 2 lbs/year credit, that buffer project credit would remain the same as an annual credit over time. If, after couple years, the HUC 12 base load has been lowered in the FFI to 475 lbs/year, and that lower value were reallocated to the stream reach scale, a similar buffer project in a reach with similar connectivity departure might be awarded a 1.9 lbs/year credit, which would remain the same as an annual credit over time. It should be noted that, because departure scores are being reduced in reaches where projects are being completed, allocations would also shift to remaining reaches where projects have not been done (where departures are still higher), and therefore, as a net effect, the credits in the reach where this second buffer project is being proposed may be very close to those before reallocation.

minimize the loss of active and passive restoration potential, when there is a broader public awareness of the functions and values that connected streams and floodplains may be serving.

3. The third step in the allocation process gives **weight to the size of a river corridor** and the degree of connectivity departure within the corridor. This brings an emphasis to a site scale and rewards those practitioners that create projects to address the most significant current-day departures.

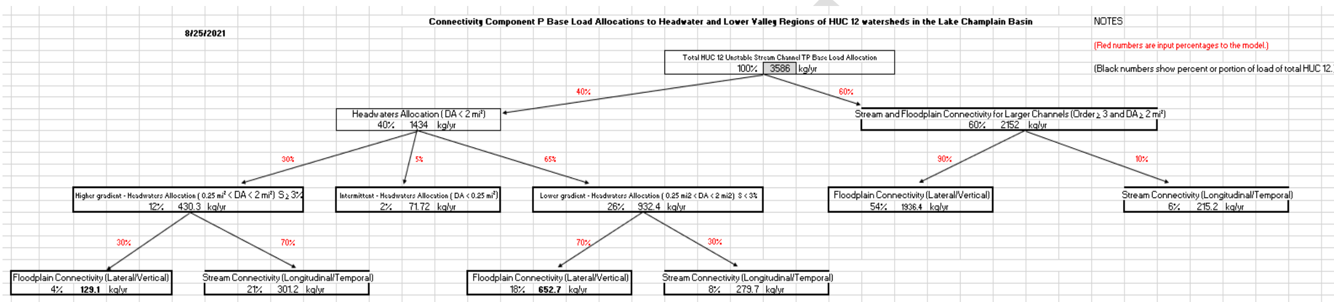

Figure 8. Overall HUC 12 base TP load allocation to connectivity components in headwater types and lower valley streams. (Enlarged snippets are shown in subsequent figures).

The overall stream stability TP load allocation process has been set up to split the HUC 12 base load down to stream and floodplain components of connectivity within headwater types and for lower valley streams. Throughout the description of this process below, enlarged snippets of the splitting process depicted in Figure 8 will be used to illustrate the text. In this example, a base load calculated for a HUC 12 in the Mad River valley from the TMDL subbasins it contains, is entered into the very top of the load splitting tree and all the connectivity component allocations are calculated.

Step 1: Allocate HUC 12 Phosphorus to Headwaters vs. Lower Valley Streams

Each HUC 12 TP unattenuated base load allocation is determined from the Lake Champlain TMDL sub-basin allocations (Figure 6). The HUC 12 load is then divided between the **headwater region** (where the drainage area (DA) is less than 2 square miles or stream order ≤ 2) and the **lower valley region** composed of larger streams and rivers (where DA ≥ 2 square miles, or stream orders ≥ 3).

Although the headwaters contain a much higher percentage of the overall stream miles in a HUC 12 (i.e., typically around 75%), they are allocated a lower percentage of the base load compared to the lower valley streams. This nonproportional allocation is primarily because the greater width and depth of TP-rich alluvium (i.e., sediment) in floodplains in lower valley settings indicate a cumulative volume that is greater than the floodplain volumes from headwater regions (Tockner and Stanford, 2002). A 60% TP base load allocation split for larger channels and 40% split for headwater channels was applied consistently across all HUC 12s (Figure 9). This split may be adjusted in outlier situations based on the percent of headwater drainage areas in the HUC 12 and the overall connectivity of lower valley or headwater streams. For example, if a HUC 12 with a high TP base load consists of very few lower valley reaches that are fairly well connected to their floodplains and a much higher percentage of headwater drainages, then a higher percentage of the HUC 12 load may be assigned to the headwaters.

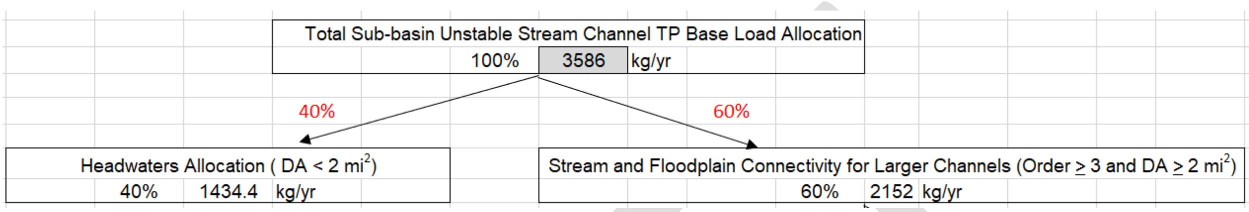

Figure 9. Example phosphorus base load allocation between the headwater regions and lower valley regions within a given HUC 12.

To provide a finer-scale allocation, the headwater region of each HUC 12 watershed is further divided into three parts with weighted allocation of TP base load (Table 12). Larger headwater streams are split into two types depending on whether channel slope is greater or less than 3 percent. [6] Steeper headwaters (**type 1**) are awarded a lower percentage of the headwater region allocation (30%), because much smaller areas are typically available in these narrower valleys for floodplain development. Stream connectivity projects in steeper headwaters (e.g., upsizing crossing structures), particularly those with greater sediment bed loads, may be more important to stability in the overall stream network. The lower gradient headwaters (**type 2**) are given a larger percentage of the headwater region allocation (65%) because (as with lower valley streams) they would typically be expected to have wider valleys and floodplain features important to channel stability and sediment storage. Floodplain connectivity projects to reduce instability and increase storage in lower gradient headwaters will be more cost-effective with a higher allocation.

Headwater allocations are further weighted by the area of stream corridor in types 1 or 2 relative to all the corridor acres in the combination of types 1 and 2. The weighting recognizes that some watersheds may be very steep or very low gradient and, for example, it would not

[6] The 3% gradient was chosen from published literature (Montgomery and Buffington, 1997) as a conservative channel slope cutoff with the intent of capturing the important pockets of floodplain, in the headwaters type 2 category, that begin forming as a stream shifts from a step-pool, sediment transport stream (narrow valley Rosgen stream type "B") to a riffle-pool, sediment deposition stream (broader valley Rosgen stream type "C").

make sense to give a large 65% allocation to 2 or 3 lower gradient reaches in an otherwise steep headwaters where the other 30 or 40 reaches are in a headwater type 1 category (>3% slope).

The headwater **type 3** (assumed to be largely comprised of intermittent streams) is given a very small allocation (5%) to support projects that restore temporal connectivity (e.g., land use conversions, gully stabilization), thereby leading to improved stream stability of down-valley perennial streams. Specific allocations for lateral, vertical, and longitudinal connectivity departures have not been made to intermittent headwater stream channels.

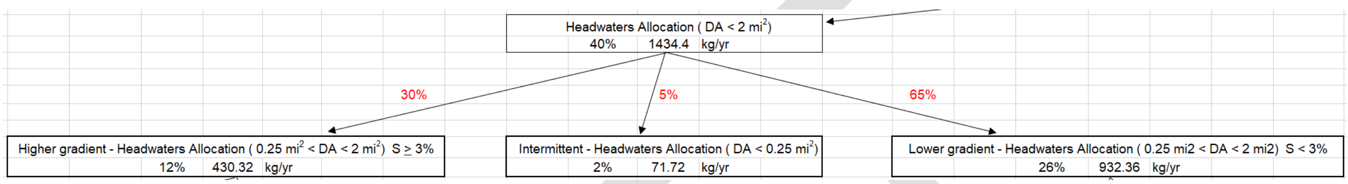

Figure 10. Example phosphorus load allocation to higher gradient headwaters, lower gradient headwaters, and intermittent streams within the headwater regions of a given HUC 12.

Step 2: Allocate Headwater and Lower Valley Phosphorus to Stream and Floodplain Connectivity Components

Allocations to each of the lower valley and headwater regions are then further split between floodplain connectivity (vertical/lateral) and stream connectivity (longitudinal/temporal) bins using FFI methods (Schiff et al., 2021). While all components of connectivity exert some influence on the full complement of forces affecting dynamic channel equilibrium (Figure 11), floodplain lateral-vertical connectivity has a greater influence over reach-scale hydraulic factors (i.e., slope, depth, and boundary resistance), while stream longitudinal-temporal connectivity has a greater influence over watershed scale inputs (i.e., discharge and sediment supply). Therefore, the P base load allocation process is started by:

1. Assigning greater lateral and vertical connectivity base loads to lower gradient stream reaches, with wider valleys and abandoned floodplains, where connectivity projects may be critical for re-storing and protecting site-specific channel slope and depth; and

2. Assigning greater longitudinal and temporal connectivity base loads to steeper headwater stream reaches where connectivity projects may be critical for re-storing natural watershed inputs (i.e., flow, sediment, and debris regimes) within the stream network.

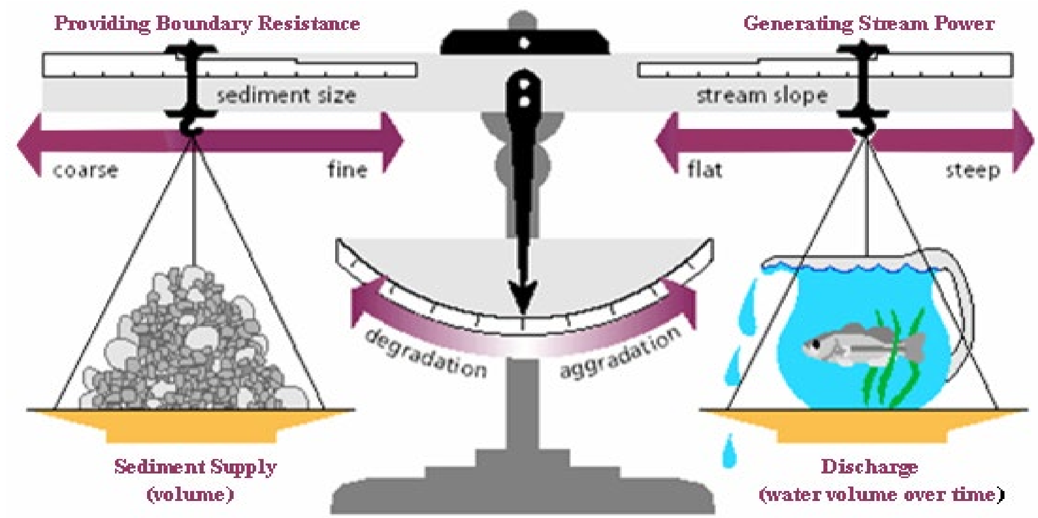

Figure 11. Lane's balance of sediment supply and sediment size with slope and discharge (Lane, 1955).

Lower Valley Stream and Floodplain Allocations. For lower valley streams, and consistent across all HUC 12s, the allocation is largely assigned to floodplain connectivity, with only a small percentage of the load assigned to stream connectivity (see the red percentages below for the P allocation split across each level). This distribution is based upon the following assumptions.

- Departures in vertical and lateral connectivity are the primary drivers of stream instability and TP loading in lower valley reaches.[7] Floodplain encroachments, and channel manipulations cause reach-scale slope and depth increases that lead to enhanced channel velocities and shear stresses and erosion of non-cohesive bed and bank sediments and P during floods.

- The cumulative impact of longitudinal and temporal departures in connectivity from upstream hydrologic alterations may drive some stream instability, but local, within-reach stream connectivity departures would have a minor impact on equilibrium conditions, unless considered cumulatively or where a larger stream is impounded behind a dam. Crossings on larger streams and rivers are typically bridges, which are less likely than culverts to create a longitudinal discontinuity in the sediment regime.

[7] Hereafter, the term stream "reach" is used in this document as shorthand for the stream sub-units, geomorphic-based stream segments and reaches used to break up the stream network in the FFI (see FFI User Manual, Fig. 2-1).

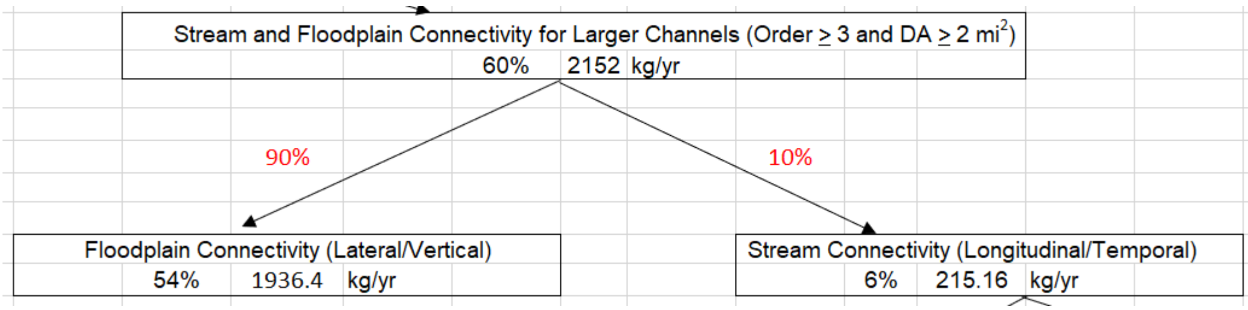

Figure 12. Example phosphorus load allocation to floodplain and stream connectivity within lower valley streams and floodplains in a given HUC 12.

<u>Headwater Stream and Floodplain Allocations</u>. Allocations between stream and floodplain connectivity have been set up differently depending on which headwater type a stream has been attributed:

- *Intermittent Stream Headwaters*: The 2% allocation of TP load from the HUC 12 base load to the intermittent stream headwater type is not further allocated between stream and floodplain connectivity. The small allocation to streams draining less the 0.25 square miles (assumed intermittent) is for crediting the land use conversions (i.e., projects that involve changing the imperviousness of the land, such as converting a ditched agricultural field to forest or restored wetland) or practices that result in the restoration of temporal connectivity. The vertical stabilization of gullies in intermittent or ephemeral streams may be considered for P load reduction credits from the land use sector in which it is located.

- *Higher Gradient Headwater Streams*: Consistent across all HUC 12s, the allocation favors stream connectivity over floodplain connectivity due to: 1) The greater prevalence and destabilizing effects of undersized culverts, dams, ditching and impervious cover expected in steeper headwaters; 2) The greater dominance of transport over deposition processes expected in steeper headwaters; and 3) The relatively smaller areal extent of floodplains and greater degree of channel boundary resistance.

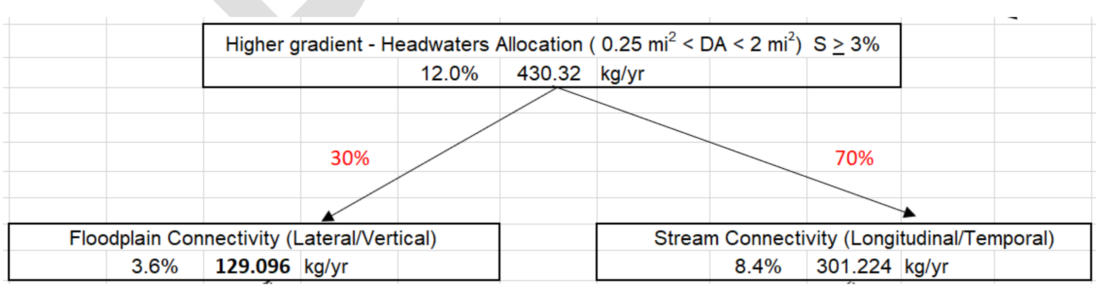

Figure 13. Example phosphorus load allocation to floodplain and stream connectivity within the higher gradient headwaters allocation of a given HUC 12.

- Lower Gradient Headwater Streams: Consistent across all HUC 12s, the allocation favors floodplain connectivity over stream connectivity. Lower gradient headwater streams, particularly in the Lake Champlain Valley, beaver influenced streams, or high-elevation wetlands may be a source of fine sediments and have significant floodplain features that are often laterally and vertically disconnected. The floodplain connectivity allocation in lower gradient headwaters streams (70%) is less than lower valley streams (90%) because the floodplain dimensions (width and depth) are proportionately lower in these settings.

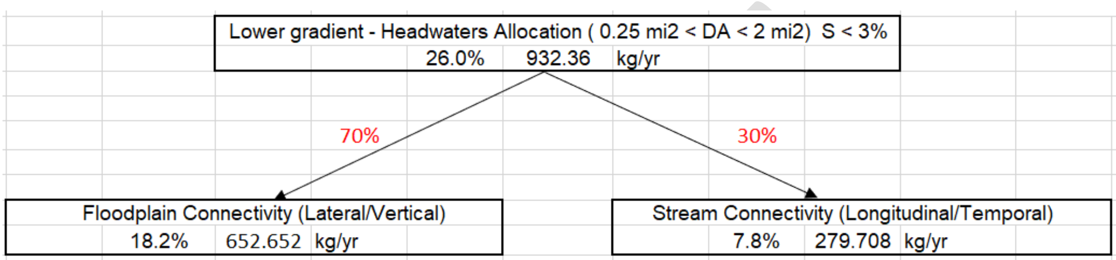

Figure 14. Example phosphorus load allocation to floodplain and stream connectivity within the lower gradient headwaters allocation of a given HUC 12.

Summary of HUC 12 P Base Load Allocations. The percentages of the HUC 12 base load allocated to floodplain and stream connectivity departures (rounded to the nearest tenth of a percent) are summarized below (Table 12).[8] These percentages would typically be the same for all HUC 12s. Because each HUC 12 allocation process would start with a different base load calculated from TMDL sub-basin loads, the application of these percentages would result in different connectivity component allocations from one HUC 12 to another.

Table 12. HUC 12 P base load allocations based on floodplain and stream connectivity. Summary tables do not include the 2 percent of the HUC 12 base load allocated to intermittent headwaters.

Higher Gradient Headwaters – 12%		Lower Gradient Headwaters - 26%	
Floodplain – 3.6%	Stream – 8.4%	Floodplain – 18.2%	Stream – 7.8%

Lower Valley Streams and Rivers – 60%	
Floodplain – 54%	Stream – 6%

[8] These summary tables do not include the 2 percent of the HUC 12 base load allocated to intermittent headwaters.

Step 3: Allocate Phosphorus to Subunits of River Corridors

This last stage of the process involves an area-weighted allocation from the floodplain or stream connectivity assigned loads based on the overall subunit (i.e., reach) floodplain or stream connectivity departure (Schiff et. al., 2021). This final allocation, used for project and passive channel evolution crediting, is based on the following formula:

$$\frac{\text{Subunit Departure Score X Subunit River Corridor Acres}}{\textit{Sum of depature scores X River corridor acres}} \text{ x Connectivity Allocation}$$

Mad River subunit M10_2_C00 Subunit departure score = 68.32 Subunit RC acres = 33.76	**HUC 041504030504 - Lower valley subunits** Sum of departure scores x RC acres = 60,227 Floodplain connectivity allocation = 1,936.4 kg/yr
Mad River subunit M10_2_C00 allocation = [(68.32 x 33.76)/60,227] x 1,936.4 kg/yr = **74.16 kg/yr**	

Figure 15. Example of a HUC 12 floodplain connectivity allocation to a lower valley Mad River subunit.

HUC 12 loads assigned to stream and floodplain connectivity are also allocated to stream reaches based on overall subunit (i.e., reach) departure scores (Schiff et. al., 2021) and weighted by the corridor area in the reach as a percentage of the corridor area within the entire lower valley or headwater type portion of the HUC 12.

While the same allocation process is used for higher-gradient and lower-gradient headwater streams (0.25 < DA < 2 square miles), the sparseness of field-measured incision ratio data (i.e., a measure of bed degradation or downcutting relative to the floodplain surface) in headwaters, has necessitated the creation of default values for incision (Table 13). These are generated using relationships between measured incision ratio data and lateral connectivity departures. [Note: These default values will be updated as field-measured values become available and as further analysis of Vermont stream geomorphic data (Kline et al., 2009) from headwaters takes place.]

Table 13. Estimated incision ratios for headwater streams.

Channel Slope	Lateral Connectivity Score	Default Incision Ratio
> 3%	0 – 100	1.25
< 3%	51 – 100	1.25
	0 – 50	1.5

Stream, Floodplain, and Wetland Restoration Project Crediting

Stream, floodplain, and wetland restoration projects do not receive one total phosphorus load reduction efficiency like other clean water projects. Instead, projects are awarded P load reduction credits for

1. the components of connectivity restored and protected (i.e., affecting stream stability); and
2. the nutrient storage achieved through restored floodplain and wetland function (see Figure 7).

The objective of these projects is restoring and protecting natural stream process, which includes a balance of erosion and deposition. So, while other clean water projects are rated for their efficiency in stopping erosion, stream stability credits are awarded based on the achievement of equilibrium through stream and floodplain connectivity. Stream stability credits for active and passive restoration receive an annual credit for the extent of the project life. Sediment/TP storage credits will decrease after year one and then remain constant.

Appendix D. Phosphorus Crediting for Stream, Floodplain, and Wetland Projects contains a detailed explanation of how groups of project types and practice are credited for the two types of P load reductions over time. *Appendix E. Incorporation of Process-Based Research into Connectivity-based P Allocations and Project Prioritization* describes how sediment regime types (Kline, 2010; Underwood et al., 2020), floodplain deposition, and wetland storage would be used to adjust allocations, project crediting, and prioritization. *Appendix F. Example Calculations for Floodplain and Stream Connectivity Projects* provides examples of how P load reduction credits are calculated within the FFI. *Appendix G. Stream Stability P Load Reduction Credits for Common Stream and Floodplain Connectivity Projects* includes an analysis of the Lake Champlain stream subunit data across the Basin to generate median P load reduction credits (lbs/acre) for some of the more common project types. These are the values also currently used for crediting in the Lake Memphremagog basin. The data in Appendix G are used to credit stream, floodplain, and wetland restoration projects in the TMDL sub-basins without a stream stability allocation (i.e., South Lake A, Port Henry, Burlington Bay, Northeast Arm, Isle La Motte) and projects in the Lake Memphremagog basin to the adjacent land use sector of the project.

Stream Stability Crediting

Floodplain and stream connectivity projects affect ongoing stream processes at both the reach and watershed scales. Therefore, once awarded, P load reduction credits against the TMDL sub-basin loads for stream stability (lb/year or kg/year) remain constant over time and are directly proportional to the increase in floodplain and/or stream connectivity score achieved by the project when it was completed. It is important to note that projects such as buffer plantings and those that disperse concentrated runoff (i.e., restore temporal connectivity) are awarded P load reduction credits because of their effects on stream stability. However, these project types may also be awarded credits in the development, agriculture, and forest sectors because they treat overland runoff and erosion. P load reductions and crediting related to overland runoff and erosion are not defined in this methodology that focuses on channel stability via dynamic equilibrium.

<u>Floodplain connectivity projects</u>. Consistent with the goal of achieving least-erosive conditions, in vertical-laterally connected streams with naturally vegetated buffers, natural sediment regime processes (see Appendix E.), and protected corridors, the project crediting system will:

- Credit projects that **remove hard constraints** in the river corridor such that lateral channel migration may occur and the stream has more space to establish a meander and channel slope more consistent with equilibrium conditions.

- Credit projects that **restore and protect 50-foot naturally vegetated buffers** and reduce channel migration to a more natural rate along vertically connected, near-equilibrium stream reaches (Appendix F. Example Calculations for Floodplain and Stream Connectivity Projects). Where the stream reach is vertically disconnected, the load reduction credit would be lower, because the lateral stability typically afforded by a naturally vegetated buffer is compromised by the depth of bank scour in the incised channel, resulting in a lower connectivity score. NOTE: while a 50-foot naturally vegetated buffer created on an incised channel would get a lower "credit" for reducing the P loading associated with stream instability, any buffer project would get a P load reduction credit for its role in slowing and infiltrating overland runoff from adjacent lands as part of a separate Watershed Project Database practice (see Forested Riparian Buffer Restoration section).

- Award all available P credits for **protecting floodplain connectivity** through the cost-effective practices of river corridor, wetland, and floodplain protection. An easement would get the lateral-protection P credits, and, because the channel evolution process would progress unimpeded (i.e., work done by the river), the project would be awarded credits for lateral meander, vertical, and naturally vegetated buffer connectivity that support stream stability (i.e., equilibrium and least erosive conditions).

- Credit projects that **raise the streambed, open a flood chute, or remove a berm** from the P load associated with the vertical connectivity departure for that reach. These projects would receive additional P load reduction credit for an increment of the annual P <u>storage</u> gained through renewed floodplain and wetland inundation processes (i.e., load reduction #2, from Figure 7).

- Projects that include **berm removal or the construction of a floodplain** through excavation would be awarded two types of P load reduction credits:

  - An annual P storage credit due to the restored inundation process (#2 in Figure 7); and

  - A stream stability credit for achieving vertical connectivity and directly moving the channel to stable evolution stages IV or V. These removed channel evolution sediments are accounted for in the FFI crediting process as the project's floodplain (lateral-vertical) connectivity P load reduction credit and contribute to reach and watershed scale equilibrium. Like other connectivity projects, constructed floodplains contribute to channel stability and storage at both the reach and watershed scale and are credited from the stream process-based P load allocation that's been established to achieve the Lake Champlain TMDL. However, these active restoration projects can be expensive, therefore, the significant co-benefits of flood damage reduction and habitat restoration will provide additional incentives for their implementation, beyond their high level of cost-effectiveness (i.e., low cost per pound of treated phosphorus compared to most other types of projects with an indefinite project life).

<u>Stream Connectivity Projects.</u> Consistent with the goal of achieving least-erosive conditions, in longitudinal-temporally connected streams with natural sediment regime processes (Appendix C), the project will be awarded P load credits from stream reach allocations proportional to the departure scores listed in the FFI User Guide (Schiff et. al., 2021) for structures and land drainage features that affect stream connectivity, and will:

- Credit projects, such as **enlarging culverts and removing or establishing operational changes at dam** or diversion structures, that restore the natural hydrology (i.e., temporal connectivity) and the longitudinal connectivity of stream processes (i.e., and the quantity, size, sorting, and distribution on sediments and debris). Severely undersized culverts on a low to moderate gradient stream may significantly disrupt the upstream to downstream flow of flood water and materials and create vertical channel instability well beyond the site of the stream crossing.

- Credit practices that reduce the erosion that occurs when a **road or agricultural drainage ditch deepens into a gully** before entering a perennial stream. These projects principally involve the treatment of stormwater (i.e., disconnecting a length of road drainage or acres of agricultural land drainage) and would be eligible for a temporal connectivity load reduction credit. Stabilization of a gully and headcuts formed by a perennial stream would receive additional stream stability credits for increasing vertical and longitudinal connectivity. Gullies that headcut into adjacent floodplains, may increase both coarse and fine sediment loads, depress groundwater levels, and adversely affect wetland hydrology. These changes, in turn, also affect stream stability by aggrading the downstream channel bed. See Appendix D for further description of stream stability crediting for Gully projects.

- Many practices that address departures in longitudinal and temporal connectivity also have a positive impact on vertical and lateral connectivity and receive credits accordingly.

Floodplain Storage Crediting

Most projects that restore connectivity between channel and floodplains improve the natural storage function of floodplains that allow for attenuation of sediment and nutrients during inundation (Opperman et al., 2010; Van Appledorn et al., 2019).

Limited sampling at recently completed floodplain reconnection sites along the Dog River, Lamoille River, and Black Creek has indicated a storage potential of 15 to 40 pounds of P per acre per year in the year(s) immediately following reconnection (unpublished empirical project data by UVM and SLR following several single event floods of an estimated 2- to 10-year recurrence interval). A literature review of floodplain restoration indicates that the longer term storage of nutrients on a floodplain drops 50% from initial reconnection values (Gellis et al., 2009). Recent research out of the University of Vermont indicates that moderately to well-connected Vermont floodplains may store between 0.2 and 30 pounds of P per acre per year (Diehl et al., 2021).

These empirically documented deposition rates are similar to values predicted using methods from other regions. A <u>potential</u> of 26 pounds P per acre per year deposited on the floodplain was estimated following the Chesapeake Bay Program floodplain crediting methods (CSN, 2020) and based on site-specific sediment and flow data for a proposed floodplain restoration project on Potash Brook in South Burlington, VT (unpublished project data prepared by Fitzgerald Environmental in 2021).

More research is needed in Vermont to refine these expected P storage values and understand the fate of deposited material and future storage potential, and emerging research on floodplain and wetland processes will be used to help prioritize FFI projects (Appendix E). In the meantime, initial storage values have been proposed for project crediting of reconnection projects (Table 14). The existing and proposed level of floodplain connectivity must be estimated to select the improvement in P storage achieved by a floodplain reconnection project. A 50% reduction of the initial credit in P storage potential for floodplains, over the lifespan of the credit, has been implemented in the table below, based on research indicating a drop off in floodplain storage following the first year of (re)connectivity (Gellis et al., 2009).

Table 14. Estimated P load reduction due to improved floodplain storage indicated by a change in floodplain connectivity (high, moderate, and low refer to floodplain connectivity scores). Storage credits to be updated by project specific measurements or future research.

	Default TP Storage Credits (lbs/acre/year)		
	Low to High	Low to Moderate	Moderate to High
Initial	20	15	10
Future (50%)	10	7	5

Floodplains deposit, store, and release sediment and nutrients that were sourced from the upstream watershed. For this reason, floodplain storage credits are given to the load allocation (e.g., developed lands, agriculture, stream stability) and waste load allocations (e.g., developed lands WLA, agriculture WLA) located upstream of a floodplain storage site. Credits are distributed based on the contribution of a) regulated vs. non-regulated loads, and b) the percent sector contribution to the base load, as reported in the TMDL for each Lake Champlain subbasin by default (EPA, 2016). However, if a project design phase determines the site-specific percentage of sector contributions upstream of the floodplain site, these more specific data may be used in crediting instead of the default percentages from the TMDL.

Watershed Management and Natural Channel Evolution Crediting

The Vermont Phase 1 Lake Champlain Phosphorus TMDL Implementation Plan (2016) explains in great detail how DEC's River, Floodplain, and Wetland programs have been enhanced to provide the regulatory and technical assistance and public outreach needed to meet the TMDL required load reductions for stream stability. The Plan states that:

> *New public policies have put the DEC Rivers and Wetland programs in the vanguard of implementing avoidance-centric approaches to watershed restoration by protecting floodplain, wetland, and riparian features where natural fluvial process enhances and sustains water, sediment, and nutrient storage.*

DEC conducts stream geomorphic assessments (SGAs) to document the status of stream processes and equilibrium conditions, as Vermont's rivers adjust in response to both human and natural stressors. The FFI framework is being developed to track the many restoration and protection projects that have become more prevalent in recent years to mitigate for past human encroachments and practices, remove constraints, and support the channel evolution process toward equilibrium and least-erosive conditions. But natural events like floods also function to remove overburden constraints and accelerate the channel evolution process. During flood recovery efforts, new public policies ensure that eroded constraints are not always replaced (e.g., FEMA buyouts), or are replaced with more geomorphically compatible structures (e.g., upsized culverts). Limits on post-flood channel dredging, windrowing, berming, and armoring are also in place, so that flood-accelerated channel evolution gains are preserved.

To capture these flood-induced changes in stream and floodplain connectivity that may not be framed as a specific restoration or protection project, per se, functionality has been built into the FFI framework to document the TP load reduction credits resulting from these flood-induced changes and acceleration of the natural channel evolution process. Post-flood SGAs have become a priority of the DEC, and after the completion of an updated assessment, River Scientists will be able to enter new and revised connectivity data from field observations into the FFI and calculate changes in P loading (lbs/year) associated with the flood-driven natural evolution of stream channels and their improved floodplain connections.

At the conclusion of an SGA, changes in the acres of (lateral) meander, protection, and buffer connectivity, subunit-scale changes in incision ratio, and changes in structures affecting longitudinal and temporal connectivity within a HUC 12 watershed would be entered in the FFI and changes in connectivity component departures would be translated into a TP load reduction from the natural channel evolution observed in the field.[9] These stream stability load reductions are reported out of the FFI for TMDL tracking by the DEC. The FFI reporting will enable the DEC to discern P load reductions made as result restoration and protection projects from those achieved through flood-driven processes and proper resource management that minimizes post-flood channelization.

Design Life

All stream, floodplain, and wetland restoration projects are designed to function in perpetuity. Therefore, the "design life" of a restoration project is the expected time it will take a project to reach a natural evolutionary stage (i.e., equilibrium) where nature takes over. The end of a design life will trigger an inspection/report for that project to ensure it is continuing to function as intended, but the benefits of the project are not expected to have an end date. The "design life" for passive restoration projects, such as an easement on an incised stream, will be 40 years, as it will take decades for the channel to evolve to its least erosive condition. The "design life" of an active restoration project, such as a constructed floodplain, dam removal, or berm removal

[9] Changes in HUC 12 connectivity scores and P load reductions from natural channel evolution would not change the P load credits awarded to projects in the SGA assessed reaches that are already in the design or implementation phase of completion. Channel evolution during floods creates connectivity that is additive and complementary to the connectivity achieved or anticipated through projects. For instance, the connectivity-based credits awarded to an easement (that protects lateral meander and buffer connectivity and anticipates vertical connectivity) stay in place and remain unchanged after a flood; however, if a post-flood assessment verifies that acres of newly connected floodplain have formed in the easement reach, then additional credits for new storage processes may be awarded following the assessment. Assessment-documented changes to connectivity and subsequent crediting would be made in non-project reaches or in project reaches where the project type did not anticipate channel evolution and therefore receive front-loaded credits.

will be 10 years as it is intended these projects will reach equilibrium more quickly. The phosphorus credit for these projects will be extended following successful verification of their functioning.

Stream, Floodplain, and Wetland Restoration Tracking & Accounting Summary

Table 15. Summary of data used for estimating phosphorus reductions from stream, floodplain, and wetland restoration projects.

Data Required	Source
Baseline phosphorus loading rate • Subunit ID • Subunit score • Subunit river corridor acres/length • Stream subunit connectivity allocation • Size/operation of structure removed/retrofitted • Subunit acres and length restored and/or protected	FFI Tool
Project credits over time • Stream stability components (meander, protection, buffer, vertical, longitudinal, temporal) • Storage component	FFI Tool
Design Life	10 years for active restoration projects 40 years for passive restoration projects

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Appendix A. Forest Road Loading Rate Development

The Lake Champlain TMDL SWAT model provided estimates of the total load from the forest sector in each lake segment watershed but was not able to partition this total load into the forest sub-categories of forest roads (primarily truck roads, skidder/forwarder trails, and log landings) and non-road forest areas. As a result, DEC contracted with Watershed Consulting Associates to develop the following more specific forest road loading rates for phosphorus accounting.

Model Selection

Following the guidelines for soil erosion model selection outlined in Fu et al. (2010), a variety of empirical and physical models were reviewed for application in this methodology. Empirical soil erosion models are based on statistical relationships between responses and independent variables, derived from empirical observations. Conversely, physical models are based on a hydrological response model that simulates infiltration and runoff routing and mass or energy conservation equations that describe erosion and sediment delivery processes (Merritt et al., 2003). Widely known and utilized empirical models include Universal Soil Loss Equation (USLE; Wischmeier and Smith, 1965), USLE-derived models (USLE-Forest; Dissmeyer and Foster, 1984), and the Revised USLE (RUSLE; Renard, 1997). Physical models that are well known and regularly utilized were evaluated including the Water Erosion Prediction Project (WEPP; Flannagan and Nearing, 1995) and WEPP-derived models (WEPP:Road; Elliot, 2004). For this application, we have determined WEPP:Road to be the most appropriate. We arrived at this decision due to the model's spatio-temporal suitability, ease of use, manageable data requirements, simple web-based interface, and ability to assess multiple road segments simultaneously via a batch import function.

The WEPP:Road model is a physical-based program that calculates erosion and sediment yield, primarily from roads, though it can be used to determine sediment yield from other practices as well as log landings. It was originally developed in 1995 by the USDA Agricultural Research Services to be used by federal action agencies in environmental planning and assessment (Flannagan and Nearing, 1995). As shown in Figure 1, the fundamental mechanics of the model describe a process by which the sediment produced from a road segment is routed over a fillslope and across a forest buffer before reaching nearby surface waters. The WEPP:Road model is particularly well suited for conditions common to forest management practices as it utilizes equations to describe the following processes:

- Infiltration and runoff,
- Soil detachment, transport, and deposition, and
- Plant growth, senescence, and residue decomposition.

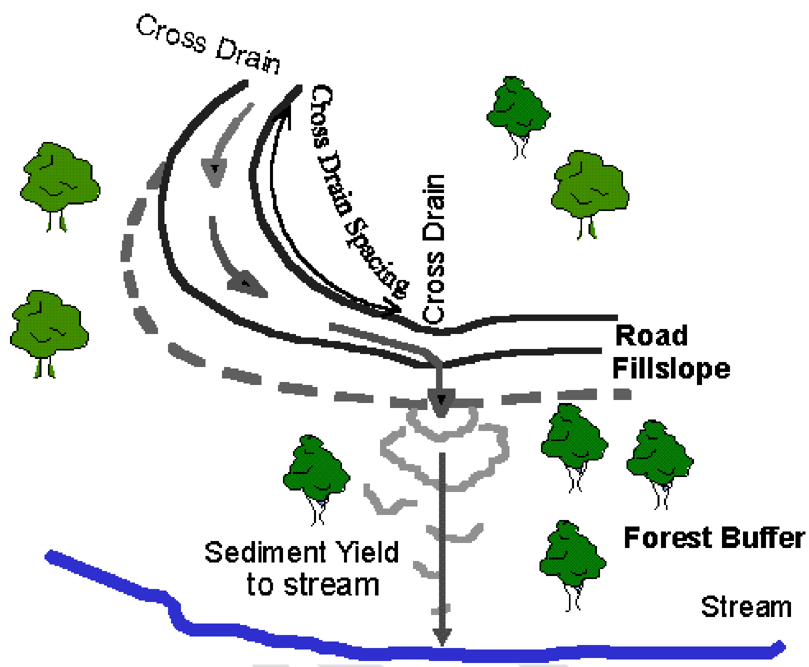

Figure 1: Template for the WEPP:Road Interface (Elliot, 2004).

WEPP:Road Model Parameters

To generalize the WEPP:Road model for the purposes of this methodology, we conducted 28,801 runs of the model using a variety of unique combinations of input variables to represent truck road conditions and 15,363 runs of the model using variables that represent skid trail conditions. The values corresponding with each input variable for both truck roads and skid trails can be found in Table 1. Certain input variables were held constant due to either their relative minimal influence on sediment yield by comparison to other variables and/or because the AMP Manual has specified constraints for said inputs. In the following subsections, we discuss each input variable at length, detailing what it means, the methods used in determining the correct value to assign, what assumptions are made, and how it is utilized in our derived methodology for determining phosphorus loads for forest road segments and UVA parcels.

The key distinctions made between truck roads and skid trails include the road surface, traffic level, road width and gradient, and fill length and gradient. Unlike truck roads, whose surface can be native soil or gravel, it is assumed that the surface of a skid trail is always native soil. Similarly, "high" traffic level is reserved for truck roads only, while skid trails commonly have traffic levels of "none" or infrequently "low". As such, the surface is assumed to be partially vegetated. It is also assumed that skid trails are narrower and steeper than truck roads. This is exemplified in the AMP Manual, which notes truck road grades should not exceed 10%, whereas skid trails should not exceed 20%. Lastly, skid trails are assumed to have no fillslope. As the WEPP:Road model requires nonzero values, a negligible fillslope length (1 ft) and grade (1%) were used.

Each of the WEPP:Road model input variables are described in Table 16 below and expounded upon in the following sections.

Table 16. WEPP:Road model input variables.

Input Variable Name	Truck Road Value(s)	Skid Trail Road Value(s)
Weather Stations	Burlington Weather Station; Montpelier Weather Station; Woodstock Weather Station; Bellows Falls Weather Station; St. Johnsbury Weather Station	Burlington Weather Station; Montpelier Weather Station; Woodstock Weather Station; Bellows Falls Weather Station; St. Johnsbury Weather Station
Soil Conditions	Loam; Sandy loam; Silt loam; Clay loam	Loam; Sandy loam; Silt loam; Clay loam
Road Design	Outsloped, rutted; Outsloped, unrutted; Insloped, bare ditch; Insloped, vegetated or rocked ditch	Outsloped, rutted; Outsloped, unrutted; Insloped, bare ditch; Insloped, vegetated or rocked ditch
Road Surface	Native; Gravel	Native
Traffic Level	High; Low; None	Low; None
Road Gradient (%)	2.5, 7.5, 15	2.5, 7.5, 15, 30
Road Length (ft)	328.084 (100 meters)	328.084 (100 meters)
Road Width (ft)	12	10
Fill Gradient (%)	50	1
Fill Length (ft)	8	1
Buffer Gradient (%)	10, 20, 30, 40	10, 20, 30, 40

Buffer Length (ft)	25, 50, 70, 90	25, 50, 70, 90

Weather Stations

For the state of Vermont, there are four climate station files built directly into the WEPP:Road model to choose from representing the climates of Burlington, Bellows Falls, Montpelier, and Woodstock regions. These files include mean monthly temperature, precipitation, and number of wet days. In our adaptation of the WEPP:Road model, each of these climate stations are used to represent the climate of the county it is located within as well as adjacent counties with similar climatic regimes (Figure 3). We further expanded the representation of climatic variability in Vermont by creating a fifth climate station for St. Johnsbury and the northeast kingdom. This was done by utilizing data taken from products produced by the U.S. National Weather Service and other national and international agencies.

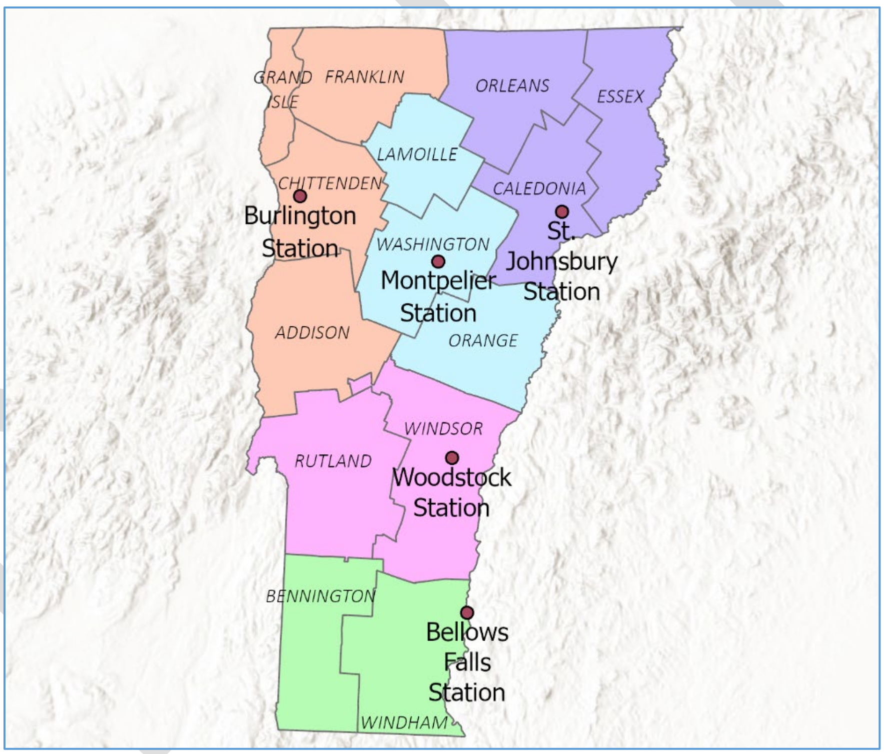

Figure 2. Distribution of five climate stations utilized in the WEPP:Road model.

Soil Conditions

Four soil textures (sandy loam, silt loam, clay loam, and loam) are listed as options for WEPP:Road model. The predominant soil texture on a UVA parcel, road segment, and adjacent buffer can be determined either by field investigation or through the USDA Web Soil Survey (Soil

Survey Staff, 2020) or the Vermont Natural Resources Atlas. Further details describing soil parameters are available in the WEPP Technical Documentation (Flanagan and Nearing, 1995).

Road Design

There are four road design options in the WEPP:Road model (Figure 4). The following section discusses the details of each of these four road designs and summarizes the relevant information to assist end-users in selecting the appropriate scenario for each modeled road segment.

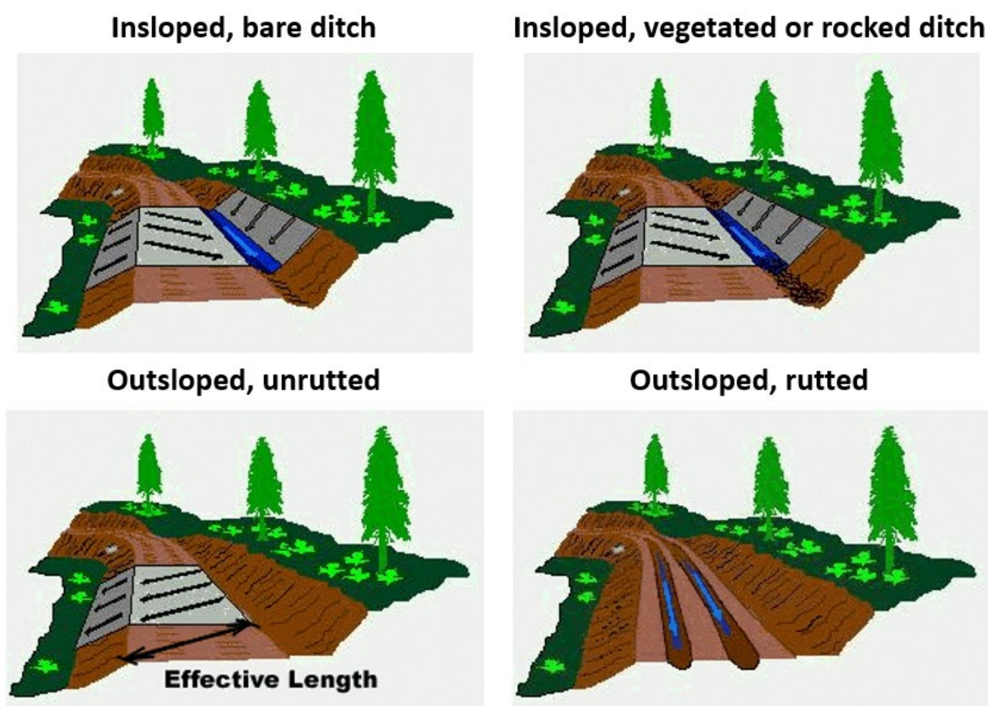

Figure 4. Diagram of flow directions for road designs in WEPP:Road program.

<u>Outsloped, unrutted.</u> The "outsloped, unrutted" design best describes the road condition immediately following blading. With traffic, however, wheel tracks soon begin to flatten, and runoff tends to follow wheel tracks--even if rutting is barely discernable--from one surface cross drain to the next. As such, the WEPP:Road model defines rutting as having a depth of 10-mm. It is important to note that this definition of rutting is built into the WEPP:Road model and does not represent any definition of rutting by FPR or DEC. In FPR's AMP Manual, a rut is simply defined as a "depression in the soils of the forest floor or depressions in dirt roads or skid trails made from the passage of any vehicles or logging equipment". The AMP manual recommends that ruts be smoothed where they are likely to result in gully erosion (>6" erosion depth) and on approaches to stream crossings. Vermont DEC does not currently define rutting depth in any capacity but does categorize erosion depth on road segments in the REI as sheet flow (<1"

erosion depth), rills (1-11” erosion depth) and gullies (>12” erosion depth). Only in cases where a road is outsloped, and traffic is light or restricted, is the "outsloped, unrutted" design appropriate. This may occur on a road that is closed, but prior to closure is bladed and outsloped.

Outsloped, rutted. The "outsloped, rutted" option generally is the most appropriate selection for an outsloped road. This road design option assumes a rill spacing of 2-m, similar to the spacing of wheel tracks. The "outsloped, rutted" design is appropriate for an insloped road with wheel ruts which are carrying runoff between cross drains where most or all runoff is not flowing into the established ditches. As this option specifies a rill spacing of 2-m, whereas the insloped design uses 4m, the predicted road erosion rates will differ.

Insloped, bare ditch. The simplest road design is the "insloped, bare ditch" design. This template assumes that there are no ruts on the road and that all runoff is diverted to an inside road ditch. Road surface erosion is due to raindrop splash and shallow overland flow, and the road ditch is experiencing rill erosion from concentrated flow. The spacing of rills on the road in the WEPP management file is set by the interface at 4m and the soil properties are assumed to be the same as those measured by field researchers (Elliot et al., 1995; Flerchinger and Watt 1987). This design is most applicable to new roads and road systems where ditch cleaning is practiced regularly. If the insloped road has wheel ruts carrying runoff between cross drains, then the "outsloped, rutted" design is more appropriate.

Insloped, vegetated or rocked ditch. The "insloped, vegetated or rocked ditch" design option uses a critical shear for the road element of $10 N\text{-}m^{-2}$. Most of the erosion occurs on the road surface due to raindrop splash and shallow overland flow. Selecting this option will generally reduce road sediment production by 50% to 90%. For example, for established roads in Oregon, Luce and Black (1999) observed that road segments with vegetated ditches delivered only 10 to 20% as much sediment as did segments with freshly graded ditches. Rock lining or vegetating a ditch is particularly effective in reducing sediment delivery at stream crossings. It is less effective in reducing delivery across a forested buffer where sediment transport by runoff rather than detachment dominates the sediment delivery. This design best models an older road where the traveled way is devoid of vegetation, but the ditches are completely covered in vegetation. It is also suited to conditions where rock or gravel is used to line the ditch to limit erosion.

Other Road Design. If the road is crowned with a ditch on either side, the erosion rate can be estimated by selecting either "insloped" (if there are no ruts) or "outsloped, rutted" (if ruts are generally present).

Road Surface

There are three options to choose from when defining the road surface in the WEPP:Road model: native, gravel, and paved. However, the methodology presented here only utilizes native and gravel material as it is unlikely that a forest road will be paved.

Native Surface. A native surface road is a road constructed from the material occurring on the site, with no added surface material. Note that unless native surface roads are regularly maintained or have little traffic, they will likely be rutted, and the "outsloped, rutted" option should be selected for the segment's road design.

Gravel Surface. A gravel surface road assumes that gravel has been added to the surface. This selection alters the soil on a road segment in the WEPP:Road model by increasing the rock content and the hydraulic conductivity of the soil as well as changing the flow path length. Generally, the increase in conductivity due to the addition of gravel decreases runoff, however in areas where runoff is due to saturated conditions rather than rainfall rates, runoff from gravel roads compared to native roads may be similar. Gravel can also reduce runoff by reducing the formation of ruts which minimizes flow path length. However, under heavy traffic, a gravel road may also become rutted. Regular maintenance or reduced tire pressure on heavy vehicles can help to maintain the desired road design.

Traffic Level

There are three road traffic level options to select from: high, low, and none. High traffic roads generally have the highest sediment loading while the rill erodibility value is reduced by 75% on roads with low or no traffic in the model. To minimize sediment generation from low use roads or roads with no traffic, the road should be outsloped and traffic restricted during wet seasons.

High Traffic. High traffic is generally associated with a timber sale, hauling numerous loads of logs over the road, or roads that receive considerable traffic during much of the year. Generally, roads with higher levels of traffic also receive regular maintenance, which may decrease rutting and erosion risk. However, high traffic can bring fines to the surface and prevent revegetation, both of which tend to increase erosion risk. High traffic roads generally have ruts or wheel tracks deep enough to assume that an "outsloped, unrutted" design is inappropriate. In most cases, a rutted design is the most appropriate for high traffic roads. The model assumes minimal vegetation on the road surface, 50% ground cover from vegetation on the fillslope, and 100% ground cover in the forest buffer.

Low Traffic. Low traffic roads are roads with administrative or light recreational use during dry weather. Low traffic roads may or may not be rutted, depending on maintenance and times of the year when the traffic occurs. The model assumes minimal vegetation on the road surface, 50% ground cover from vegetation on the fillslope, and 100% ground cover in the forest buffer.

No Traffic. No traffic roads are roads with restricted or no access. For no traffic, we assume the road has at least 50% vegetative cover, and the fillslope and forest buffer both have 100% vegetative ground cover.

Road Gradient

One of the most influential variables in the WEPP:Road model is road gradient. In this methodology, we break truck road gradient down into three categories, gradual (0-5%), moderate (5-10%), and steep (>10%). For skid trails, "steep" is defined as 11-20% and "very steep" is anything greater than 20%. An upper limit of 10% for truck roads and 20% for skid trails is used as the AMP manual recommends avoiding gradients greater than these values.

As shown in Table 11, the model input value we use for each of these categories is the average slope of each category, for example sediment production from gradual roads (0-5%) are calculated using a gradient of 2.5%.

In this methodology we advise that slope is estimated using elevation data in the VT ANR Atlas or within a GIS and verified during audit inspections.

Road Length and Width

Of the topographical input variables for roads, both road length and width are held constant. Road length is the defining feature of how road segments are split, and road width is held constant due to specifications derived from the Vermont AMP manual.

Fill Gradient and Length

Fill gradient describes the percent slope of the fill slope surface. Fill length is the horizontal length of fill slope. Both values are held constant as their relative influence on loading is less than some other variables and their specifications are defined in the Vermont AMP Manual.

Buffer Gradient and Length

Forest buffers, protective strips, buffer strips, filter strips, or riparian management zones are interchangeable terms for areas of forested land adjacent to streams and other bodies of water. The input variables used for buffer length and gradient in this methodology are based on those outlined in the Vermont AMP manual (). These variables are highly critical to this analysis as they are the two variables that determine the percent of the sediment and phosphorus load that reaches a nearby body of water (Rhee, 2014). In this methodology, we advise that buffer length be determined as the smallest distance between a road segment and a stream, perpendicular to the stream beginning at the mean high watermark or the landward edge of an active flood plain or wetland (Figure 5). If the distance between a road segment and a stream is variable along the length of the segment, the shortest distance will be utilized as shown in Figure 6. Similar to road gradient, we advise that slope is estimated using elevation data in the VT ANR Atlas or within a GIS and verified during audit inspections.

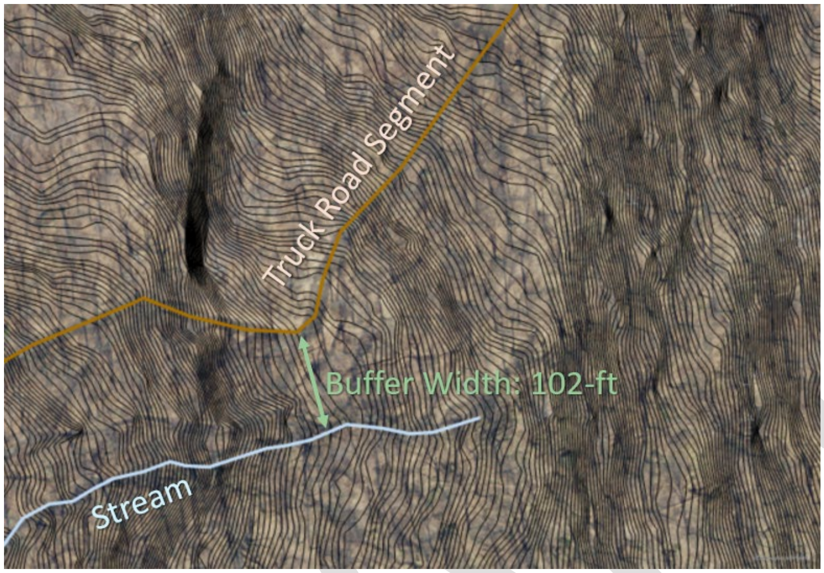

Figure 16. Buffer width example.

TABLE 4

Minimum Forest Buffer Widths

Percent Slope of Land Between Skid Trails, Truck Roads or Log Landings and Streams or Other Waters	Width from Top of Bank (Feet Along Surface of Ground Measured Perpendicular to the Stream or Other Waters)
0-10	50
11-20	70
21-30	90
31-40*	110

*Add 20 feet for each additional 10 percent slope

Remember that the buffer distance is measured on each side of the stream. For example, if one side of the stream is 7% slope, the buffer distance on that side is 50 feet. If the other side is 15% slope, the buffer distance on that side is 70 feet. The total forest buffer width at location on the stream is 120 feet.

Forest Buffer

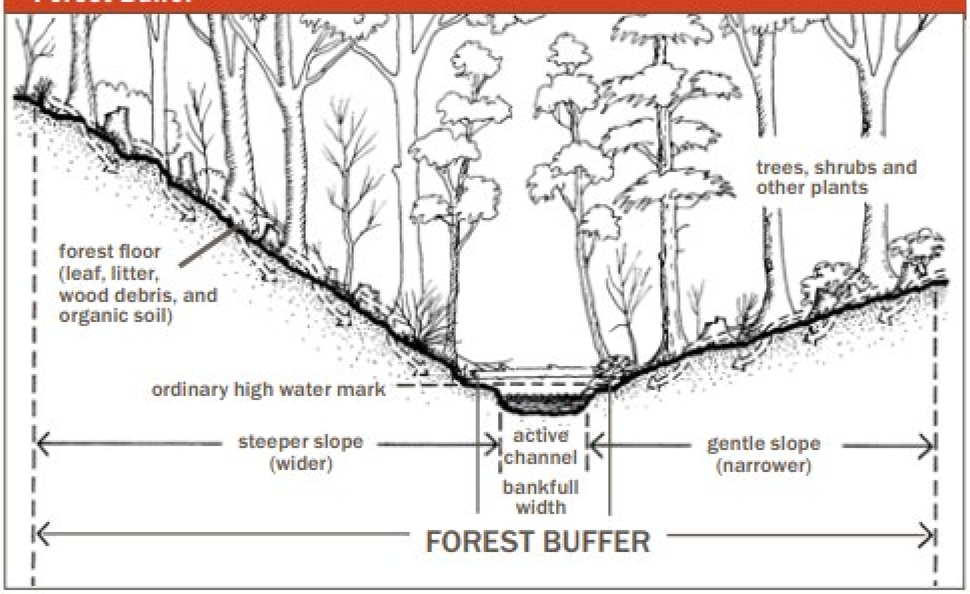

Figure 17. Vermont AMP Forest Buffer Specifications.

Phosphorus/Sediment Production

In the WEPP:Road model, the phosphorus and sediment production from a road segment is primarily driven by four key influential variables: road design, traffic level, weather station, and road gradient. For the sake of simplicity in this methodology for road segments, traffic level and road design are combined into a term we designate as "runoff potential". There are four categories of runoff potential as displayed in Table 17 below.

Table 17. Forest Road runoff potential for road segments.

Runoff Potential	Classification
Very High	Traffic Level = "High"
High	Traffic Level = "Low" **&** Road Design = "Insloped, bare ditch" or "Outsloped, rutted"
Medium	Traffic Level = "Low" **&** Road Design = "Insloped, vegetated or rocked ditch" or "Outsloped, unrutted" ***OR…*** Traffic Level = "None" **&** Road Design = "Insloped, bare ditch" or "Outsloped, rutted"
Low	Traffic Level = "None" **&** Road Design = "Insloped, vegetated or rocked ditch" or "Outsloped, unrutted"

Either through field assessments or existing information, the appropriate road design and traffic level are assigned to each road segment, resulting in its runoff potential designation. This, when compared to the average road gradient can be then used to determine the phosphorus and sediment production (kg/100m/year) as found in the tables of Appendix B for truck roads and Appendix C for skid trails. These tables represent the mean phosphorus and sediment production calculated across all other input variables.

One key element to note is that the phosphorus production is not a direct output of the WEPP:Road model, but rather a conversion determined through an assumed direct linear relationship between sediment and phosphorus load as shown in the following equation. This conversion factor is derived from Wemple et al (2013). This same conversion factor is utilized in the Vermont DEC Road Erosion Inventory accounting methodology for unpaved roads and is similar to the Michigan Department of Transportation (MDOT) conversion factor of (0.0005 kg P / kg TSS). Additionally, this conversion factor is used for forest phosphorus loads in the SWAT model developed for the Lake Champlain TMDLs by Tetra Tech (2015). Phosphorus loads derived from a road segment per county can be found in Table 6. This is strictly the phosphorus produced from a road segment, not the load that enters a nearby body of water.

$$Phosphorus\ Load\ [kg] = Sediment\ Load\ [kg] * 0.000396$$

Percentage of Phosphorus/Sediment to Reach a Waterbody

To estimate the percent of phosphorus and sediment reaching a waterbody, the initial phosphorus and sediment production load needs to be multiplied by the percentage determined by the forest buffer length and forest buffer gradient as found in the Truck roads sediment and Phosphorous tables in this Appendix. It is important to note that we classify all roads farther than 100-ft from a water of the state or wetland as hydrologically disconnected. This is approximate to the MRGP method which defines hydrologically connected roads as those within 100ft of a water of the state or wetland. Conversely, to estimate the sediment delivery for a road segment with a stream crossing, the user can assume that all of the road prism erosion enters the stream. This method does not include any erosion from the fill slope.

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Truck Roads Sediment and Phosphorus Tables

Table A-1: Estimated sediment production leaving the road (kg/100m/year) for Grand Isle, Franklin, Chittenden, and Addison counties.

Grand Isle, Franklin, Chittenden, and Addison County			
Runoff Potential	*Predominant Soil Type*	Loam	
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	336.35	855.20	2384.64
High	178.26	422.51	1068.75
Moderate	98.87	233.28	621.63
Low	66.24	103.25	278.36
Runoff Potential	*Predominant Soil Type*	Sandy Loam	
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	136.76	344.16	1036.28
High	80.63	186.46	485.38
Moderate	63.52	125.30	340.42
Low	53.72	84.52	193.32
Runoff Potential	*Predominant Soil Type*	Silt Loam	
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	322.80	809.44	2067.40
High	156.84	361.61	812.30
Moderate	88.10	198.07	512.22
Low	62.88	99.28	249.50
Runoff Potential	*Predominant Soil Type*	Clay Loam	
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	302.74	733.64	1961.35
High	143.10	339.35	867.32
Moderate	78.67	172.84	467.89
Low	53.72	82.93	202.46

Table A-2: Estimated phosphorus production leaving the road (kg/100m/year) for Grand Isle, Franklin, Chittenden, and Addison counties.

Grand Isle, Franklin, Chittenden, and Addison County			
Runoff Potential	*Predominant Soil Type* Loam		
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	0.133	0.339	0.944
High	0.071	0.167	0.423
Moderate	0.039	0.092	0.246
Low	0.026	0.041	0.110
Runoff Potential	Predominant Soil Type Sandy Loam		
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	0.054	0.136	0.410
High	0.032	0.074	0.192
Moderate	0.025	0.050	0.135
Low	0.021	0.033	0.077
Runoff Potential	Predominant Soil Type Silt Loam		
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	0.128	0.321	0.819
High	0.062	0.143	0.322
Moderate	0.035	0.078	0.203
Low	0.025	0.039	0.099
Runoff Potential	Predominant Soil Type Clay Loam		
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	0.120	0.291	0.777
High	0.057	0.134	0.343
Moderate	0.031	0.068	0.185
Low	0.021	0.033	0.080

Table A-3: Percent of phosphorus and sediment from road segments that reaches a nearby waterbody for Grand Isle, Franklin, Chittenden, and Addison counties.

Grand Isle, Franklin, Chittenden, and Addison County						
Forest Buffer Gradient	*Predominant Soil:* Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	55%	34%	29%	27%	0%
11-20%	100%	67%	42%	32%	28%	0%
21-30%	100%	71%	57%	40%	36%	0%
31-40%	100%	74%	62%	52%	47%	0%
Forest Buffer Gradient	*Predominant Soil:* Sandy Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	48%	40%	35%	30%	0%
11-20%	100%	61%	49%	45%	44%	0%
21-30%	100%	73%	64%	58%	54%	0%
31-40%	100%	79%	71%	68%	70%	0%
Forest Buffer Gradient	*Predominant Soil:* Silt Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	63%	41%	36%	34%	0%
11-20%	100%	71%	48%	39%	37%	0%
21-30%	100%	78%	54%	45%	37%	0%
31-40%	100%	80%	67%	59%	53%	0%
Forest Buffer Gradient	*Predominant Soil:* Clay Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	67%	46%	35%	30%	0%
11-20%	100%	74%	52%	40%	33%	0%
21-30%	100%	76%	62%	50%	44%	0%
31-40%	100%	79%	67%	57%	50%	0%

Table A-4: Estimated sediment production leaving the road (kg/100m/year) in Lamoille, Washington, and Orange counties.

Lamoille, Washington, and Orange County			
Runoff Potential	*Predominant Soil Type* Loam		
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	446.06	1060.63	2591.30
High	235.50	512.76	1093.20
Moderate	126.79	289.11	718.98
Low	83.10	130.32	345.27
Runoff Potential	*Predominant Soil Type* Sandy Loam		
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	274.97	625.82	1563.60
High	177.38	348.01	717.80
Moderate	105.06	222.87	524.62
Low	78.78	123.72	285.28
Runoff Potential	*Predominant Soil Type* Silt Loam		
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	471.11	1053.23	2685.39
High	223.53	458.60	1041.87
Moderate	119.32	255.34	641.89
Low	80.54	123.73	314.50
Runoff Potential	*Predominant Soil Type* Clay Loam		
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	399.86	883.06	2054.61
High	175.71	384.67	842.35
Moderate	96.65	209.34	524.74
Low	67.62	102.63	246.79

Table A-5: Estimated <u>phosphorus</u> production leaving the road (kg/100m/year) in Lamoille, Washington, and Orange counties.

Lamoille, Washington, and Orange County			
Runoff Potential	*Predominant Soil Type*	Loam	
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	0.177	0.420	1.026
High	0.093	0.203	0.433
Moderate	0.050	0.114	0.285
Low	0.033	0.052	0.137
Runoff Potential	Predominant Soil Type	Sandy Loam	
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	0.109	0.248	0.619
High	0.070	0.138	0.284
Moderate	0.042	0.088	0.208
Low	0.031	0.049	0.113
Runoff Potential	Predominant Soil Type	Silt Loam	
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	0.187	0.417	1.063
High	0.089	0.182	0.413
Moderate	0.047	0.101	0.254
Low	0.032	0.049	0.125
Runoff Potential	Predominant Soil Type	Clay Loam	
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	0.158	0.350	0.814
High	0.070	0.152	0.334
Moderate	0.038	0.083	0.208
Low	0.027	0.041	0.098

Table A-6: Percent of phosphorus and sediment from road segments that reaches a nearby waterbody in Lamoille, Washington, and Orange counties.

Lamoille, Washington, and Orange County						
Forest Buffer Gradient	*Predominant Soil:* Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	69%	46%	37%	33%	0%
11-20%	100%	76%	56%	44%	38%	0%
21-30%	100%	79%	66%	57%	50%	0%
31-40%	100%	83%	71%	65%	59%	0%
Forest Buffer Gradient	*Predominant Soil:* Sandy Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	52%	40%	32%	28%	0%
11-20%	100%	68%	54%	47%	40%	0%
21-30%	100%	76%	66%	66%	63%	0%
31-40%	100%	80%	72%	69%	67%	0%
Forest Buffer Gradient	*Predominant Soil:* Silt Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	72%	54%	44%	38%	0%
11-20%	100%	80%	60%	50%	43%	0%
21-30%	100%	83%	71%	62%	51%	0%
31-40%	100%	85%	76%	70%	63%	0%
Forest Buffer Gradient	*Predominant Soil:* Clay Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	78%	62%	51%	46%	0%
11-20%	100%	82%	70%	59%	52%	0%
21-30%	100%	83%	73%	66%	62%	0%
31-40%	100%	86%	78%	70%	67%	0%

Table A-7: Estimated <u>sediment</u> production leaving the road (kg/100m/year) in Orleans, Essex, and Caledonia counties.

Orleans, Essex and Caledonia County			
Runoff Potential	*Predominant Soil Type* Loam		
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	529.78	1283.78	3442.09
High	287.79	642.07	1532.04
Moderate	153.80	337.04	852.59
Low	97.84	154.08	393.61
Runoff Potential	*Predominant Soil Type* Sandy Loam		
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	293.05	717.74	1924.51
High	197.94	405.82	904.75
Moderate	127.75	260.03	630.65
Low	98.28	155.49	354.11
Runoff Potential	*Predominant Soil Type* Silt Loam		
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	554.42	1294.83	3608.50
High	268.32	580.78	1455.17
Moderate	144.73	312.07	787.31
Low	95.59	147.91	366.70
Runoff Potential	*Predominant Soil Type* Clay Loam		
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	494.57	1097.02	2832.44
High	216.54	491.08	1207.54
Moderate	119.79	258.54	662.20
Low	80.13	121.71	299.48

Table A-8: Estimated <u>phosphorus</u> production leaving the road (kg/100m/year) in Orleans, Essex, and Caledonia counties.

Orleans, Essex and Caledonia County			
Runoff Potential	*Predominant Soil Type* Loam		
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	0.210	0.508	1.363
High	0.114	0.254	0.607
Moderate	0.061	0.133	0.338
Low	0.039	0.061	0.156
Runoff Potential	Predominant Soil Type Sandy Loam		
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	0.116	0.284	0.762
High	0.078	0.161	0.358
Moderate	0.051	0.103	0.250
Low	0.039	0.062	0.140
Runoff Potential	Predominant Soil Type Silt Loam		
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	0.220	0.513	1.429
High	0.106	0.230	0.576
Moderate	0.057	0.124	0.312
Low	0.038	0.059	0.145
Runoff Potential	Predominant Soil Type Clay Loam		
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	0.196	0.434	1.122
High	0.086	0.194	0.478
Moderate	0.047	0.102	0.262
Low	0.032	0.048	0.119

Table A-9: Percent of phosphorus and sediment from road segments that reaches a nearby waterbody in Orleans, Essex, and Caledonia counties.

Orleans, Essex and Caledonia County						
Forest Buffer Gradient	*Predominant Soil:* Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	74%	52%	43%	37%	0%
11-20%	100%	78%	62%	54%	51%	0%
21-30%	100%	83%	70%	62%	57%	0%
31-40%	100%	88%	77%	71%	66%	0%
Forest Buffer Gradient	*Predominant Soil:* Sandy Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	63%	47%	38%	32%	0%
11-20%	100%	75%	65%	62%	54%	0%
21-30%	100%	81%	73%	67%	67%	0%
31-40%	100%	87%	79%	74%	72%	0%
Forest Buffer Gradient	*Predominant Soil:* Silt Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	76%	60%	49%	43%	0%
11-20%	100%	81%	68%	57%	50%	0%
21-30%	100%	83%	72%	65%	60%	0%
31-40%	100%	88%	78%	71%	69%	0%
Forest Buffer Gradient	*Predominant Soil:* Clay Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	79%	69%	61%	54%	0%
11-20%	100%	81%	73%	67%	58%	0%
21-30%	100%	84%	77%	71%	64%	0%
31-40%	100%	87%	81%	77%	72%	0%

Table A-10: Estimated sediment production leaving the road (kg/100m/year) in Rutland and Windsor counties.

Rutland and Windsor County			
Runoff Potential	*Predominant Soil Type* Loam		
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	273.24	745.21	2248.52
High	156.42	383.10	1030.66
Moderate	67.77	187.34	572.87
Low	41.62	59.02	191.93
Runoff Potential	*Predominant Soil Type* Sandy Loam		
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	96.16	318.29	988.94
High	79.55	192.74	465.33
Moderate	34.49	94.18	282.48
Low	25.24	36.69	102.00
Runoff Potential	*Predominant Soil Type* Silt Loam		
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	268.08	736.95	2274.86
High	142.67	338.85	928.45
Moderate	60.32	151.66	491.55
Low	38.36	52.21	161.44
Runoff Potential	*Predominant Soil Type* Clay Loam		
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	252.67	647.05	1797.02
High	118.39	309.56	814.13
Moderate	53.20	142.50	430.42
Low	34.63	46.96	137.30

Table A-11: Estimated phosphorus production leaving the road (kg/100m/year) in Rutland and Windsor counties.

Rutland and Windsor County			
Runoff Potential	*Predominant Soil Type*	Loam	
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	0.108	0.295	0.890
High	0.062	0.152	0.408
Moderate	0.027	0.074	0.227
Low	0.016	0.023	0.076
Runoff Potential	Predominant Soil Type	Sandy Loam	
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	0.038	0.126	0.392
High	0.032	0.076	0.184
Moderate	0.014	0.037	0.112
Low	0.010	0.015	0.040
Runoff Potential	Predominant Soil Type	Silt Loam	
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	0.106	0.292	0.901
High	0.056	0.134	0.368
Moderate	0.024	0.060	0.195
Low	0.015	0.021	0.064
Runoff Potential	Predominant Soil Type	Clay Loam	
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	0.100	0.256	0.712
High	0.047	0.123	0.322
Moderate	0.021	0.056	0.170
Low	0.014	0.019	0.054

Table A-12: Percent of phosphorus and sediment from road segments that reaches a nearby waterbody in Rutland and Windsor counties.

Rutland and Windsor County						
Forest Buffer Gradient	*Predominant Soil:* Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	58%	41%	27%	20%	0%
11-20%	100%	64%	47%	34%	27%	0%
21-30%	100%	68%	55%	45%	36%	0%
31-40%	100%	77%	63%	56%	49%	0%
Forest Buffer Gradient	*Predominant Soil:* Sandy Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	41%	26%	17%	5%	0%
11-20%	100%	53%	40%	31%	25%	0%
21-30%	100%	64%	51%	43%	38%	0%
31-40%	100%	72%	61%	54%	49%	0%
Forest Buffer Gradient	*Predominant Soil:* Silt Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	64%	51%	42%	30%	0%
11-20%	100%	70%	57%	49%	39%	0%
21-30%	100%	74%	61%	54%	45%	0%
31-40%	100%	79%	66%	59%	53%	0%
Forest Buffer Gradient	*Predominant Soil:* Clay Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	66%	52%	43%	36%	0%
11-20%	100%	70%	56%	49%	41%	0%
21-30%	100%	76%	60%	52%	46%	0%
31-40%	100%	82%	67%	60%	53%	0%

Table A-13: Estimated sediment production leaving the road (kg/100m/year) in Bennington and Windham counties.

Bennington and Windham County			
Runoff Potential	*Predominant Soil Type* Loam		
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	518.54	1254.66	3440.30
High	288.76	638.43	1578.51
Moderate	155.47	331.37	837.99
Low	98.44	148.99	377.83
Runoff Potential	*Predominant Soil Type* Sandy Loam		
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	284.03	716.90	1872.89
High	189.23	399.75	884.63
Moderate	124.81	264.80	612.22
Low	95.58	151.78	342.43
Runoff Potential	*Predominant Soil Type* Silt Loam		
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	540.80	1283.93	3625.92
High	268.87	584.44	1478.17
Moderate	140.49	295.87	772.25
Low	91.28	143.84	354.45
Runoff Potential	*Predominant Soil Type* Clay Loam		
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	473.40	1059.42	2776.52
High	212.82	483.64	1201.47
Moderate	115.56	250.25	643.18
Low	76.00	115.95	280.97

Table A-14: Estimated phosphorus production leaving the road (kg/100m/year) in Bennington and Windham counties.

Bennington and Windham County			
Runoff Potential	*Predominant Soil Type*	Loam	
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	0.205	0.497	1.362
High	0.114	0.253	0.625
Moderate	0.062	0.131	0.332
Low	0.039	0.059	0.150
Runoff Potential	Predominant Soil Type	Sandy Loam	
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	0.112	0.284	0.742
High	0.075	0.158	0.350
Moderate	0.049	0.105	0.242
Low	0.038	0.060	0.136
Runoff Potential	Predominant Soil Type	Silt Loam	
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	0.214	0.508	1.436
High	0.106	0.231	0.585
Moderate	0.056	0.117	0.306
Low	0.036	0.057	0.140
Runoff Potential	Predominant Soil Type	Clay Loam	
	Road Segment Gradient		
	Gradual Slope (<%5)	Moderate Slope (5-10%)	Steep Slope (>10%)
Very High	0.187	0.420	1.100
High	0.084	0.192	0.476
Moderate	0.046	0.099	0.255
Low	0.030	0.046	0.111

Table A-15: Percent of phosphorus and sediment from road segments that reaches a nearby waterbody in Bennington and Windham counties.

Bennington and Windham County						
Forest Buffer Gradient	*Predominant Soil:* Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	74%	53%	43%	38%	0%
11-20%	100%	79%	62%	55%	50%	0%
21-30%	100%	83%	70%	63%	58%	0%
31-40%	100%	88%	77%	71%	68%	0%
Forest Buffer Gradient	*Predominant Soil:* Sandy Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	63%	48%	40%	33%	0%
11-20%	100%	73%	66%	63%	55%	0%
21-30%	100%	81%	73%	69%	69%	0%
31-40%	100%	86%	78%	75%	74%	0%
Forest Buffer Gradient	*Predominant Soil:* Silt Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	77%	61%	50%	46%	0%
11-20%	100%	81%	70%	57%	52%	0%
21-30%	100%	86%	75%	68%	64%	0%
31-40%	100%	91%	80%	75%	72%	0%
Forest Buffer Gradient	*Predominant Soil:* Clay Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	80%	69%	60%	54%	0%
11-20%	100%	83%	75%	65%	59%	0%
21-30%	100%	86%	78%	71%	64%	0%
31-40%	100%	89%	83%	78%	72%	0%

Skid Trails Sediment and Phosphorus Tables

Table A-19: Estimated sediment production leaving the skid trail (kg/100m/year) in Grand Isle, Franklin, Chittenden, and Addison counties.

Grand Isle, Franklin, Chittenden, and Addison County				
	Predominant Soil Type	Loam		
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	121.76	408.30	1000.44	2242.28
Moderate	72.80	199.90	544.54	1241.55
Low	52.09	83.25	194.25	520.85
	Predominant Soil Type	Sandy Loam		
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	48.36	113.58	317.44	633.53
Moderate	43.69	81.70	190.62	407.94
Low	43.35	63.16	116.69	223.82
	Predominant Soil Type	Silt Loam		
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	107.36	343.74	791.43	1583.32
Moderate	68.01	169.57	441.54	1030.91
Low	55.41	81.18	173.97	453.22
	Predominant Soil Type	Clay Loam		
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	99.18	339.24	877.20	1761.78
Moderate	55.92	146.94	403.65	948.25
Low	40.65	62.45	129.91	352.30

Table A-20: Estimated phosphorus production leaving the skid trail (kg/100m/year) in Grand Isle, Franklin, Chittenden, and Addison counties.

Grand Isle, Franklin, Chittenden, and Addison County				
	Predominant Soil Type	Loam		
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	0.048	0.162	0.436	0.888
Moderate	0.029	0.079	0.216	0.492
Low	0.021	0.033	0.077	0.206
	Predominant Soil Type	Sandy Loam		
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	0.019	0.045	0.126	0.251
Moderate	0.017	0.032	0.075	0.162
Low	0.017	0.025	0.046	0.089
	Predominant Soil Type	Silt Loam		
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	0.043	0.136	0.313	0.627
Moderate	0.027	0.067	0.175	0.408
Low	0.022	0.032	0.069	0.179
	Predominant Soil Type	Clay Loam		
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	0.039	0.134	0.347	0.698
Moderate	0.022	0.058	0.160	0.376
Low	0.016	0.025	0.051	0.140

Table A-21: Percent of phosphorus and sediment from skid trail segments that reaches a nearby waterbody in Grand Isle, Franklin, Chittenden, and Addison counties.

Grand Isle, Franklin, Chittenden, and Addison County						
Forest Buffer Gradient	*Predominant Soil:*	Loam				
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	55%	29%	19%	17%	0%
11-20%	100%	63%	38%	23%	19%	0%
21-30%	100%	66%	45%	28%	25%	0%
31-40%	100%	68%	51%	38%	28%	0%
Forest Buffer Gradient	*Predominant Soil:*	Sandy Loam				
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	34%	18%	8%	1%	0%
11-20%	100%	45%	32%	21%	9%	0%
21-30%	100%	52%	41%	30%	23%	0%
31-40%	100%	59%	55%	46%	41%	0%
Forest Buffer Gradient	*Predominant Soil:*	Silt Loam				
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	55%	31%	23%	18%	0%
11-20%	100%	62%	39%	27%	20%	0%
21-30%	100%	67%	42%	34%	22%	0%
31-40%	100%	69%	52%	41%	29%	0%
Forest Buffer Gradient	*Predominant Soil:*	Clay Loam				
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	62%	47%	31%	25%	0%
11-20%	100%	68%	55%	35%	29%	0%
21-30%	100%	70%	60%	41%	34%	0%
31-40%	100%	71%	65%	49%	40%	0%

Table A-22: Estimated <u>sediment</u> production leaving the skid trail (kg/100m/year) in Lamoille, Washington, and Orange counties.

Lamoille, Washington, and Orange County				
Runoff Potential	*Predominant Soil Type*	Loam		
	Road Segment Gradient			
	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	165.32	444.32	1025.53	1905.98
Moderate	89.93	233.12	581.00	1251.52
Low	58.53	92.90	224.02	578.02
Runoff Potential	*Predominant Soil Type*	Sandy Loam		
	Road Segment Gradient			
	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	88.15	216.60	484.66	869.31
Moderate	71.94	139.25	318.00	636.78
Low	63.53	97.76	183.07	363.19
Runoff Potential	*Predominant Soil Type*	Silt Loam		
	Road Segment Gradient			
	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	141.04	389.24	948.15	1823.01
Moderate	79.95	205.94	513.76	1144.00
Low	58.44	89.90	206.75	530.73
Runoff Potential	*Predominant Soil Type*	Clay Loam		
	Road Segment Gradient			
	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	122.21	337.12	733.00	1396.82
Moderate	68.44	171.57	413.39	901.90
Low	45.60	72.50	150.95	394.82

Table A-23: Estimated phosphorus production leaving the skid trail (kg/100m/year) in Lamoille, Washington, and Orange counties.

Lamoille, Washington, and Orange County				
	Predominant Soil Type	Loam		
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	0.065	0.176	0.406	0.755
Moderate	0.036	0.092	0.230	0.496
Low	0.023	0.037	0.089	0.229
	Predominant Soil Type	Sandy Loam		
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	0.035	0.086	0.192	0.344
Moderate	0.028	0.055	0.126	0.252
Low	0.025	0.039	0.072	0.144
	Predominant Soil Type	Silt Loam		
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	0.056	0.154	0.375	0.722
Moderate	0.032	0.082	0.203	0.453
Low	0.023	0.036	0.082	0.210
	Predominant Soil Type	Clay Loam		
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	0.048	0.133	0.290	0.553
Moderate	0.027	0.068	0.164	0.357
Low	0.018	0.029	0.060	0.156

Table A-24: Percent of phosphorus and sediment from skid trail segments that reaches a nearby waterbody in Lamoille, Washington, and Orange counties.

Lamoille, Washington, and Orange County						
Forest Buffer Gradient	*Predominant Soil:* Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	60%	43%	31%	26%	0%
11-20%	100%	69%	50%	37%	28%	0%
21-30%	100%	72%	56%	42%	33%	0%
31-40%	100%	73%	62%	48%	39%	0%
Forest Buffer Gradient	*Predominant Soil:* Sandy Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	43%	28%	20%	15%	0%
11-20%	100%	53%	41%	32%	26%	0%
21-30%	100%	65%	54%	47%	39%	0%
31-40%	100%	65%	59%	59%	50%	0%
Forest Buffer Gradient	*Predominant Soil:* Silt Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	63%	48%	40%	32%	0%
11-20%	100%	70%	56%	49%	36%	0%
21-30%	100%	74%	61%	53%	42%	0%
31-40%	100%	76%	65%	59%	47%	0%
Forest Buffer Gradient	*Predominant Soil:* Clay Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	66%	54%	43%	38%	0%
11-20%	100%	72%	61%	50%	44%	0%
21-30%	100%	74%	66%	54%	51%	0%
31-40%	100%	75%	69%	59%	54%	0%

Table A-25: Estimated sediment production leaving the skid trail (kg/100m/year) in Orleans, Essex, and Caledonia counties.

Orleans, Essex, and Caledonia County				
	Predominant Soil Type	Loam		
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	187.14	575.69	1477.82	3004.20
Moderate	100.43	269.10	707.99	1541.39
Low	63.49	106.32	253.63	662.46
	Predominant Soil Type	Sandy Loam		
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	109.73	245.18	553.16	1068.88
Moderate	88.15	172.84	371.46	714.19
Low	76.12	118.34	224.94	440.81
	Predominant Soil Type	Silt Loam		
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	158.54	496.29	1346.66	2770.23
Moderate	90.40	231.47	640.09	1425.64
Low	63.02	100.67	238.41	621.92
	Predominant Soil Type	Clay Loam		
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	148.23	458.85	1146.57	2258.19
Moderate	76.34	208.06	548.32	1195.42
Low	45.27	75.96	186.99	496.10

Table A-26: Estimated phosphorus production leaving the skid trail (kg/100m/year) in Orleans, Essex, and Caledonia counties.

Orleans, Essex, and Caledonia County				
Runoff Potential	*Predominant Soil Type*	Loam		
	Road Segment Gradient			
	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	0.074	0.228	0.585	1.190
Moderate	0.040	0.107	0.280	0.610
Low	0.025	0.042	0.100	0.262
Runoff Potential	*Predominant Soil Type*	Sandy Loam		
	Road Segment Gradient			
	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	0.043	0.097	0.219	0.423
Moderate	0.035	0.068	0.147	0.283
Low	0.030	0.047	0.089	0.175
Runoff Potential	*Predominant Soil Type*	Silt Loam		
	Road Segment Gradient			
	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	0.063	0.197	0.533	1.097
Moderate	0.036	0.092	0.253	0.565
Low	0.025	0.040	0.094	0.246
Runoff Potential	*Predominant Soil Type*	Clay Loam		
	Road Segment Gradient			
	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	0.059	0.182	0.454	0.894
Moderate	0.030	0.082	0.217	0.473
Low	0.018	0.030	0.074	0.196

Table A-27: Percent of phosphorus and sediment from skid trail segments that reaches a nearby waterbody in Orleans, Essex, and Caledonia counties.

Orleans, Essex, and Caledonia County						
Forest Buffer Gradient	*Predominant Soil:* Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	64%	47%	37%	31%	0%
11-20%	100%	71%	53%	42%	36%	0%
21-30%	100%	74%	55%	46%	42%	0%
31-40%	100%	77%	61%	52%	45%	0%
Forest Buffer Gradient	*Predominant Soil:* Sandy Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	43%	33%	24%	20%	0%
11-20%	100%	55%	49%	38%	31%	0%
21-30%	100%	62%	61%	52%	47%	0%
31-40%	100%	67%	57%	58%	53%	0%
Forest Buffer Gradient	*Predominant Soil:* Silt Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	67%	52%	43%	37%	0%
11-20%	100%	73%	61%	50%	45%	0%
21-30%	100%	76%	65%	55%	49%	0%
31-40%	100%	79%	70%	58%	52%	0%
Forest Buffer Gradient	*Predominant Soil:* Clay Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	70%	58%	49%	44%	0%
11-20%	100%	74%	65%	56%	50%	0%
21-30%	100%	76%	68%	59%	55%	0%
31-40%	100%	78%	71%	65%	59%	0%

Table A-28: Estimated sediment production leaving the skid trail (kg/100m/year) in Rutland and Windsor counties.

Rutland and Windsor County				
	Predominant Soil Type Loam			
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	125.91	392.27	1066.38	2220.96
Moderate	59.28	177.80	525.01	1276.84
Low	42.14	56.00	141.59	480.58
	Predominant Soil Type Sandy Loam			
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	36.12	101.32	283.08	607.83
Moderate	22.16	52.82	158.15	374.89
Low	20.26	28.46	56.29	159.24
	Predominant Soil Type Silt Loam			
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	103.50	329.59	929.67	1978.58
Moderate	50.20	154.86	456.67	1122.10
Low	40.60	52.96	131.47	429.38
	Predominant Soil Type Clay Loam			
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	106.25	327.15	824.22	1666.62
Moderate	49.60	150.54	417.50	980.89
Low	32.21	44.27	105.08	347.65

Table A-29: Estimated phosphorus production leaving the skid trail (kg/100m/year) in Rutland and Windsor counties.

Rutland and Windsor County				
	Predominant Soil Type	Loam		
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	0.050	0.155	0.422	0.879
Moderate	0.023	0.070	0.208	0.506
Low	0.017	0.022	0.056	0.190
	Predominant Soil Type	Sandy Loam		
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	0.014	0.040	0.112	0.241
Moderate	0.009	0.021	0.063	0.148
Low	0.008	0.011	0.022	0.063
	Predominant Soil Type	Silt Loam		
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	0.041	0.131	0.368	0.784
Moderate	0.020	0.061	0.181	0.444
Low	0.016	0.021	0.052	0.170
	Predominant Soil Type	Clay Loam		
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	0.042	0.130	0.326	0.660
Moderate	0.020	0.060	0.165	0.388
Low	0.013	0.018	0.042	0.138

Table A-30: Percent of phosphorus and sediment from skid trail segments that reaches a nearby waterbody in Rutland and Windsor counties.

Rutland and Windsor County						
Forest Buffer Gradient	*Predominant Soil:* Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	56%	37%	24%	17%	0%
11-20%	100%	63%	43%	31%	21%	0%
21-30%	100%	66%	49%	34%	25%	0%
31-40%	100%	70%	52%	43%	35%	0%
Forest Buffer Gradient	*Predominant Soil:* Sandy Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	19%	12%	3%	6%	0%
11-20%	100%	27%	20%	8%	3%	0%
21-30%	100%	37%	27%	15%	15%	0%
31-40%	100%	43%	28%	26%	22%	0%
Forest Buffer Gradient	*Predominant Soil:* Silt Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	59%	43%	30%	25%	0%
11-20%	100%	66%	50%	35%	28%	0%
21-30%	100%	69%	55%	42%	33%	0%
31-40%	100%	72%	58%	49%	37%	0%
Forest Buffer Gradient	*Predominant Soil:* Clay Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	62%	51%	38%	29%	0%
11-20%	100%	67%	58%	47%	33%	0%
21-30%	100%	69%	61%	51%	38%	0%
31-40%	100%	71%	63%	54%	46%	0%

Table A-31: Estimated sediment production leaving the skid trail (kg/100m/year) in Bennington and Windham counties.

Bennington and Windham County				
	Predominant Soil Type	Loam		
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	181.73	569.41	1487.47	3053.71
Moderate	96.88	256.82	678.87	1502.00
Low	62.04	101.02	236.63	634.14
	Predominant Soil Type	Sandy Loam		
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	105.25	238.79	573.71	1099.80
Moderate	86.59	167.64	365.59	702.68
Low	74.49	116.28	217.99	430.12
	Predominant Soil Type	Silt Loam		
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	150.96	489.21	1341.14	2802.77
Moderate	86.55	222.40	611.17	1400.58
Low	61.86	96.57	223.73	589.91
	Predominant Soil Type	Clay Loam		
	Road Segment Gradient			
Runoff Potential	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	146.14	456.88	1159.00	2317.37
Moderate	73.09	202.13	545.40	1187.23
Low	44.07	73.10	181.48	479.49

Table A-32: Estimated phosphorus production leaving the skid trail (kg/100m/year) in Bennington and Windham counties.

Bennington and Windham County				
Runoff Potential	*Predominant Soil Type*	Loam		
	Road Segment Gradient			
	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	0.072	0.225	0.589	1.209
Moderate	0.038	0.102	0.269	0.595
Low	0.025	0.040	0.094	0.251
Runoff Potential	*Predominant Soil Type*	Sandy Loam		
	Road Segment Gradient			
	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	0.042	0.095	0.227	0.436
Moderate	0.034	0.066	0.145	0.278
Low	0.029	0.046	0.086	0.170
Runoff Potential	*Predominant Soil Type*	Silt Loam		
	Road Segment Gradient			
	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	0.060	0.194	0.531	1.100
Moderate	0.034	0.088	0.242	0.555
Low	0.024	0.038	0.089	0.234
Runoff Potential	*Predominant Soil Type*	Clay Loam		
	Road Segment Gradient			
	Gradual Slope (<5%)	Moderate Slope (5-10%)	Steep Slope (11-20%)	Very Steep Slope (>20%)
High	0.058	0.181	0.459	0.918
Moderate	0.029	0.080	0.216	0.470
Low	0.017	0.029	0.072	0.190

Table A-33: Percent of phosphorus and sediment from skid trail segments that reaches a nearby waterbody in Bennington and Windham counties.

Bennington and Windham County						
Forest Buffer Gradient	*Predominant Soil:* Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	65%	47%	37%	31%	0%
11-20%	100%	70%	53%	42%	36%	0%
21-30%	100%	72%	57%	48%	41%	0%
31-40%	100%	77%	63%	55%	47%	0%
Forest Buffer Gradient	*Predominant Soil:* Sandy Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	45%	34%	25%	20%	0%
11-20%	100%	57%	47%	38%	32%	0%
21-30%	100%	61%	58%	54%	49%	0%
31-40%	100%	65%	60%	59%	56%	0%
Forest Buffer Gradient	*Predominant Soil:* Silt Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	66%	52%	44%	38%	0%
11-20%	100%	72%	60%	51%	45%	0%
21-30%	100%	75%	67%	56%	49%	0%
31-40%	100%	78%	71%	595	54%	0%
Forest Buffer Gradient	*Predominant Soil:* Clay Loam					
	Stream Crossing	25 – 49ft	50 – 69ft	70 – 89ft	90 – 100ft	>100ft
0-10%	100%	70%	60%	50%	45%	0%
11-20%	100%	74%	66%	57%	51%	0%
21-30%	100%	75%	68%	62%	55%	0%
31-40%	100%	78%	71%	65%	59%	0%

Appendix B. Forestland Audit Questions & UVA Crosswalk

Audit Questions by Category	Required	Not Required	N/A	Notes
Crossings				
Are approaches stable and unlikely to contribute sediment to the stream?	x			
Are culvert pipes installed properly in the channel to avoid undercutting and channel erosion?	x			Most closely associated with properly sized culvert.
Are culverts and bridges of adequate length?	x			Length and width don't apply equally to bridges and culverts.
Are culverts covered with adequate and appropriate fill material?	x			Adequate and appropriate fill is present if it is stable. It is required to be stable.
Are culverts covered with gravel to reduce erosion near the stream?		x		Culverts are frequently stable without gravel (vegetated, for example).
Are culverts properly sized according to the BMP manual Tables 6 and 7 or Talbot's formula?	x			
Are fords used only where a natural rock base (or geoweb) and gentle approaches allow?	x			Functionally equivalent requirement (stable bed in stream)
Are head walls stabilized with vegetation, rock or fabric to minimize cutting?	x			
Are permanent bridge abutments adequate and stable?	x			
Are stream banks and approaches re-claimed with sufficient vegetation, rock or slash?	x			
Are stream crossings installed at or near to right angles where possible?	x			
Are stream crossings minimized?		x		
Are temporary culverts, pole bridges and bridges removed?	x			
Are water diversion structures present when needed on approaches?	x			
Do all ford crossings avoid restricting the natural flow of water?	x			
Do all ford crossings have a 50-foot approach of clean gravel?	x			Yes, gravel or equivalently stable road base.
Do all ford crossings have underlying geo-textile where needed (on approaches)?	x			Approaches must be stable.

Is the addition of unnatural materials in the stream to facilitate the use of a ford minimized?	x			
Were pole bridges used only in appropriate circumstances?	x			
Decks				
Are all decks limited in size?		x		
Are all log decks located at least 50 feet from the nearest SMZ.	x			
Are appropriate soil protection measures in place to prevent erosion on the deck?	x			
Are decks reshaped where needed to ensure drainage?	x			
Are fluid spills from equipment minimal?		x		No clear point of reference as to what is "minimal".
Are log decks located on relatively well-drained ground with low to moderate slopes?	x			
Are sediment trapping structures present if needed to prevent pollution?	x			
Are water diversion structures installed to prevent water from crossing the deck?	x			
Is the deck free of trash, garbage and other non-slash debris related to the harvest operation?			x	This generally isn't related to water quality.
Planning				
In the case of severe site conditions (very wet or steep) was the harvesting system modified to reduce damage to soil, site and water?	x			
Is there evidence or knowledge of a harvest plan (painted lines, flagging, delineated hazards, SMZs or decks, engineered roads, etc...)?			x	
Is there evidence that the logger utilized a harvesting system that is generally appropriate for the site and timber conditions?	x			
Roads				
Are grades between 2% and 10% except for necessary deviations?	x			
Are new roads located and constructed to allow for proper drainage?	x			
Are new roads located to avoid erodible, wet and sensitive ground?	x			
Are riprap and/or brush dams used where needed to slow water and trap sediment?	x			Yes, or equivalent functional strategy. Needed in

				hydrologically connected areas.
Are roads built outside of SMZs where possible?	x			
Are roads daylighted where needed and feasible?		x		
Are roads in SMZs as far from the channel as possible and built to prevent stream sedimentation?	x			
Are roads on the contour where practical?	x			Yes, or equivalent appropriate layout needs.
Are roads out-sloped where needed and conditions allow?	x			
Are temporary roads retired with properly constructed water bars or tank traps?	x			
Are turnouts directing water and/or sediment away from riparian areas?	x			At proper distance (riparian area is sometimes the buffer).
Are under-road culverts installed, spaced and maintained properly?	x			
Is access being controlled with a functional gate or barrier?		x		Only necessary if such access affects soil stability - uses not defined.
Is construction of dips, bars, turnouts and traps adequate to maintain function?	x			
Is gravel or vegetation present to protect water bars from erosion?	x			
Is there rock or vegetation on slopes where needed to prevent erosion?	x			Yes, or equivalently functional strategy to stabilize.
Is water being “turned out” into surrounding landscape with appropriate structures?	x			
Is water diverted from the road surface at specified intervals using dips, bars or traps?	x			
Was road construction and use minimized?		x		No reference for what constitutes "minimized."
Skidding				
Are all skid trails free from channelized flow that is likely to cause sedimentation?	x			
Are all skid trails located outside the SMZ?	x			
Are appropriate cross drainages installed where springs or seeps crossed the trails?	x			

Are bladed skid trails limited to less than 26% grade unless absolutely necessary?	x			
Are bladed skid trails limited to side slopes less than 60%?		x		
Are un-bladed trails limited to side slopes less than 36% in general?		x		
Are water bars established on trails where erosion is likely at recommended intervals?	x			
Are water turnouts built to ensure drainage of skid trails where needed?	x			
Did the logger avoid skidding logs through intermittent or perennial streams?	x			
Do trails avoid long, continuous grades?	x			We have defined long continuous grades as slopes over 20% greater than 300'.
Do trails avoid rutting that will likely cause channelized erosion near a stream?	x			
Is vegetation established where needed on trails to prevent erosion and sedimentation?	x			Needed at crossings.
Were brush mats used to stabilize trails and prevent erosion where needed?	x			Yes, or equivalent strategy.
Stream Management Zones (Forest Buffers)				
Are all SMZs a minimum of 50 feet wide on each side of the stream bank?	x			
Are SMZ widths modified to accommodate cold water fisheries and municipal water supplies?		x		
Did the logger avoid exposing large sections of soil in the SMZ?	x			
Did the logger avoid partial or patch clear cutting in the SMZ?	x			
Did the logger avoid silvicultural debris in the stream that would warrant a law enforcement action under the "debris in the stream law?"	x			
Did the logger avoid silvicultural sediment in the stream that might endanger public health, beneficial uses or aquatic life as stated in the "silvicultural water quality law?"	x			
Do all intermittent and perennial streams have an SMZ?	x			
Do all sinkholes or karst features have an SMZ?			x	No karst or sink holes.

Does at least 50% of the original basal area exist in the SMZ?	x			
In tidal areas, has a 50-foot SMZ been maintained from the grass or marsh edge?			x	No tidal areas.
Is SMZ width relatively consistent along the entire length?	x			Yes, based on consistent minimum buffer width being met.
Is the SMZ free of roads and landings where possible?	x			
Was exposed soil in the SMZ re-vegetated or covered with organic materials?	x			
Wetlands				
Are landings located on appropriate ground?	x			
Did operations in wetlands avoid altering hydrology of the site to such a degree as to convert a wetland to a non-wetland?	x			
Did the operation avoid activities during particularly wet weather?			x	Do not evaluate day-by-day operation.
Is water movement maintained on the site?	x			
Was low ground pressure equipment (LGP) utilized where needed?	x			
Was the harvesting system appropriate for the site conditions?	x			
Were the 15 mandatory road BMPs followed for wetland roads?	x			Yes, based on substitution with adherence to Vermont Wetland Rules and Forestry Allowed Uses
Were the six mandatory site prep BMPs followed as needed?			x	Different state standard - no VT equivalent

Appendix C. Lake Champlain TMDL Stream Sector Assumptions

Excerpted From:

Lake Champlain BMP Scenario Tool: Requirements and Design. Prepared by Tetra Tech Inc. for U.S. EPA, Region 1. (April 2015) (pp. 27-30) and correspondence with Eric Perkins (US EPA, VT TMDL Coordinator, Water Quality and Wetlands Protection Section)

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.

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 reaches. 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. 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 reaches are at stage III than at stage II (49 versus 11).

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.

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).

Summary from Eric Perkins (EPA) in correspondence with VT DEC:

"Loading rates (from unstable streams) were modeled using a customized SWAT routine, as described in the SWAT report. The loading rates are by HUC-12 reach, there's no areal loading rate. I worked with DEC Rivers Program and Tetra Tech to then match stream channel evolution model (CEM) status info with loading rates, so that we could understand the estimated P reduction if a stream reach goes from an unstable class like CEM III to an equilibrium class, like CEM I. So, the plan was not to track P reductions associated with individual shoreline or streambank stabilization projects, but rather to track overall improvement in a reach (as a result of a combination of practices implemented). If VT river scientists determine that a combination of practices has changed a reach from class III to I, for example, or even part way there, the P reduction could be estimated based on the assumed percentage change between those classes (applying that percent reduction to the baseline load for the reach). This was the original plan. I'll just add for context that VTDEC felt this overall approach was superior to the approach used in the Chesapeake in part because the Chesapeake approach doesn't easily take into account the impacts an individual streambank project may have on other parts of the stream system – as you know, stabilizing a bank in one spot can make erosion worse downstream etc, depending how well the project is integrated with an overall stream system restoration plan. And Vermont is in the rare position to have sufficient stream geomorphic assessment data to evaluate progress over time at the reach level in many or most cases. From a tracking standpoint, the intent was for DEC to keep track of projects done in each HUC-12 reach, and then maybe every 5 years (or perhaps longer, depending on activity in a particular reach), the DEC rivers scientist that covers the applicable reach would do an assessment of progress towards equilibrium conditions. If it is found that a reach is about half-way toward CEM I, for example, then credit would be given for one half of the difference between the baseline load and the estimated load associated with attaining CEM I."

Appendix D. Phosphorus Crediting for Stream, Floodplain, and Wetland Projects

The following tables describing P load reductions over time strictly follow the expected pattern as a stream project reach might evolve toward dynamic equilibrium. A crediting system that followed the same timeframes would require many resources dedicated to project monitoring and administrative tasks. Therefore, from years of assessing channel evolution processes in Vermont, streams evolve to their least erosive form over time, therefore DEC will award these anticipated stream stability credits starting at the completion of a project.

Projects with similar patterns of P load reductions and credits are grouped below, and tables are provided for each group to show P load reductions for year 1, years 2-40, and years 41 and beyond associated with stream stability and floodplain storage. Projects crediting beyond 40 years is stable as 40 years is the average time to return to equilibrium across project types. Where the type and design of a project cannot always anticipate additional stream stability and storage credits, project monitoring will be needed to document load reductions and the award of additional credits for new floodplain function—stream stability and storage credits.

Smaller dots • and larger triangles▼ are used to show the relative size of a credit between connectivity components, project types, and time periods. Some groups include large projects where certain practice types always occur concurrently, i.e., floodplain excavations with corridor protections. Where this is not the case, separate project group credits may be applied, if they happen to occur concurrently (e.g., if the removal of a small dam happens to also include an easement to protect the newly created floodplain, the project would get the credits described in Groups 2 and 6 below).

Crediting by Project Types

Stream stability connectivity components in the tables below are represented as follows: M=meander; P=protection; B=buffer; V=vertical; L=longitudinal; S=structure (temporal); D=development (temporal); and A=agriculture (temporal).

Group 1: **A. Floodplain and channel restoration;**
B. Large/medium dam removal

Group 1A	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability[10]	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
		•	•	▼				•		•	•	▼				•		•	•	▼				•
Storage	▼								•								•							

Group 1B	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
		•	•	▼	▼	▼		•		•	•	▼	▼	▼		•		•	•	▼	▼	▼		•
Storage	▼								•								•							

Steam Stability – These large restoration projects would get credits for vertical reconnection, lateral protection, riparian buffer, and possibly temporal connectivity for land use conversion that would remain constant over time. Large and medium-sized dam removal projects that significantly restore longitudinal and temporal (structural) connectivity would get these credits which would remain constant over time.

Storage – These projects would all restore inundation and storage processes and get a per acre P storage credit that would be higher in year one. Starting in year two, storage would be awarded a lower value (reflecting a lower efficiency) that would then remain constant over time.

Group 2: Remove small intact Run-Of-River or breached dam

Group 2	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
		•	•	▼	▼	▼				•	•	▼	▼	▼				•	•	▼	▼	▼		

[10] Stream stability connectivity components: M=meander; P=protection; B=buffer; V=vertical; L=longitudinal; S=structure (temporal); D=development (temporal); and A=agriculture (temporal)

Storage	▼	•	•

Steam Stability – Small dam removal projects would get credits for vertical reconnection, lateral protection, riparian buffer, and possibly temporal connectivity for land use conversion that would remain constant over time. Small and breached dam removal projects that significantly restore longitudinal and temporal (structural) connectivity would get these credits and they would remain constant over time.

Storage – These projects would all restore inundation and storage processes and get a per acre P storage credit that would be higher in year one. Starting in year two, storage would be awarded a lower value (reflecting a lower efficiency) that would then remain constant over time.

<u>Group 3</u>: **Reconnect flood chute; Remove berm; Create flood bench; or Raise channel**

Group 3	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
			•	▼							•	▼							•	▼				
Storage	▼								•								•							

Steam Stability – Projects that create floodplain access would get a vertical connectivity and a riparian buffer credit. Floodplain connectivity credits would remain constant over time.

Storage – these projects would typically restore inundation and storage processes (with some berm removals being the exception) and get a per acre P storage credit that would be higher in year one. Starting in year two, storage would be awarded a lower value (reflecting a lower efficiency) that would then remain constant over time.

<u>Group 4</u>: **Restore channel roughness; or Large wood addition (e.g., chop and drop, or beaver analog)**

Group 4	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
				•								▼								▼				
Storage									•								•							

Steam Stability – Channel roughness and wood addition projects have the potential to significantly alter channel hydraulics and result in aggradation of sediments and debris that restore floodplain function and channel stability. Should this process occur, the project would get a vertical connectivity credit that may increase over time. Crediting for this group of project types would necessitate monitoring.

Storage – If floodplain reconnection occurs the project would get a per acre P load storage credit.

Group 5: **Remove hard constraint to meander migration**

Group 5	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
	▼	•							▼	•							▼	•						
Storage	•								•								•							

Steam Stability – Removing hard constraints and protecting the land from future development, that would otherwise result in stream channelization, armoring and expected channel disequilibrium, would get credit for lateral protection and meander connectivity that would remain constant over time.

Storage – If the project occurs on lands where the stream and floodplain are vertically connected, the project will receive a per acre P storage credit where removal of the hard constraint has opened access to the previously-isolated natural floodplain.

Group 6: **River corridor easement**

Group 6	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
		•	•	▼						•	•	▼						•	•	▼				•
Storage																	•							

Steam Stability – River corridor easement projects would get a lateral connectivity credit for protection and buffer that would remain constant over time. Easements would also get front-loaded credits for anticipated vertical connectivity. In some reaches where easements are being completed, vertical connectivity may already exist (i.e., therefore, new vertical connectivity credits would not be awarded, only lateral), on others it would be anticipated to occur over time given the easement conditions limiting any new channel of river corridor encroachments.

Storage – As floodplains reform through the channel evolution process, the project would receive per acre P storage credits.

Group 7: **Adopt a river corridor bylaw; or**

Conserve wetlands (e.g., NRCS Wetland Reserve)

Group 7	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
		•								•								•						
Storage																								

Steam Stability – Providing a moderate level of protection, i.e., little or no new structural encroachment, where there was little or no protection, would garner a small lateral protection connectivity credit. The benefit of river corridor bylaws would be the cumulative credits awarded for protecting stream reaches throughout a municipality. Wetland conservation, without any restoration practices, is included in this group, because protecting an already functioning wetland would assure a modest benefit to stream stability over time, there may be no additional increase stream stability as a result.

Storage – No new storage would be anticipated for simple administrative constraints (e.g., legal agreements) to conserve a functioning wetland. In the case of both river corridor bylaws and wetland conservation, however, any change on channelization or drainage maintenance practices stemming from the change in land use, may enhance stream processes where floodplain formation, inundation, and storage functions would increase over time.

Group 8: **A. Plant 50-foot natural vegetation buffer or stabilize a streambank[11]; or**
B. Plant natural vegetation within the entire river corridor or floodplain

Group 8A	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
			•								•								•					
Storage																								

Group 8B	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
			•					•			•					•			•					•
Storage									•								•							

[11] Streambank stabilization (including a bank armoring practice) would be predicated on the river being at or beyond the limits of the of the meander belt within the river corridor delineation and would get a Group 8 credit, the same as a 50 ft buffer, if the banks being armored are for a channel that is vertically and laterally connected.

Steam Stability – Planting natural vegetation within a 50′ riparian buffer would receive a lateral connectivity credit. Credits for buffer and bank stabilization[3] projects on vertically connected streams would be higher than those on incised streams. Projects that involve the revegetation of the entire width of the river corridor or floodplain would also be awarded temporal connectivity credits for land use conversion. [Note: To incentivize these projects and reduced monitoring and administrative expense, buffer projects would begin receiving the full credit associated with a mature buffer upfront upon completion of the planting.]

Storage – Along with infiltrating and storing water (i.e., decreasing peak stream flows), inundation processes would be affected within a revegetated river corridor/floodplain, thereby increasing sediment/P storage. A modest storage credit may be anticipated for plantings in the corridor/floodplain outside the 50-ft buffer.

Please note that buffers also receive overland flow and land use conversion crediting, as described in the "Forested Riparian Buffer Restoration" section of this document.

Group 9: **A. Replace bridges and culverts – bankfull span and/or steep slope; or**
B. Replace bridges and culverts – undersized and/or shallow slope

Group 9A	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
					•	•							•	•							•	•		
Storage																								

Group 9B	Year 1								Years 2 - 9								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
				•	▼	•						•	▼	•						•	▼	•		
Storage																	•							

Steam Stability – Bridges and culverts affect longitudinal and temporal flows in the channel, the floodplain, or both. Crossings with span lengths at or near channel bankfull width mostly affect larger flood flows and their replacement would be awarded only modest longitudinal and temporal credits. Minor breaks in the natural connectivity of flows may also occur at structures crossing steeper sloped channels, and credits would be awarded accordingly. The replacement of undersized crossings, especially culverts and structures that impound flood flows and disrupt sediment transport, would receive higher longitudinal connectivity credits. If replacement of the severely undersized culvert changes sediment regime processes above and below the crossing, the downstream deposition result in the restoration of vertical connectivity then stream stability credit may be awarded.

Storage – If floodplains reform or reconnect through the channel evolution process, the project would receive per acre P storage credits.

Group 10: **Stabilize Headcut in Perennial Stream; or Stabilize Gully (with perennial flow)**

Group 10	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
				•	▼							•	▼							•	▼			
Storage																								

Steam Stability – Headcut and/or gully stabilizations are unique because the objective is to try and arrest the erosion process at the project site, and, in-so-doing promote equilibrium at the reach and watershed scale. These projects may be awarded a modest vertical connectivity credit and a more significant longitudinal credit.

Storage – No new storage would be anticipated with a headcut or gully stabilization project.

Group 11: **Removal of ditch and tile drainage from Wetlands; Stabilize gully resulting from stormwater (intermittent/ephemeral flow); Disconnect municipal or private road ditch; or Treat legacy forest trail/road drainage**

Group 11	Year 1								Years 2 - 40								Years ≥ 41							
Stream Stability	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
							•	•							•	•							•	•
Storage	▼								•								•							

Steam Stability – The restoration of wetlands and projects that divert and infiltrate stormwater from developed or agricultural lands, that would otherwise enter a drainage ditch, form a gully, and enter a perennial stream, would be credited for restoring the temporal connectivity of the watershed.

Storage – Wetland restoration would be credited for increasing P storage. Other stormwater treatment projects would not create new storage—related to flood inundation process—and would not be awarded storage credits.

Note that gullies resulting from stormwater runoff and municipal/private road improvements are also credited in the Developed Lands sector. Please see the "Outfall and Gully Stabilization" and "Road Erosion Remediation" BMPs in the Developed Lands SOP for more information.

Note that municipal and private roads legacy forest road and trail drainage improvements are also credited to the forest load allocation under the "Forest Road Erosion Control" BMP described above.

Group 12: Remove or re-permit stream diversions or water withdrawals; or Remove groundwater extraction (commercial, wells)

Group 12	Year 1								Years 2 - 40								Years ≥ 41							
	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A	M	P	B	V	L	S	D	A
Stream Stability					•	•							•	•							•	•		
Storage																								

Steam Stability – Removing or changing the operation of structures that divert surface or subsurface flows from the stream would be awarded credits for improving longitudinal and temporal connectivity that would begin in year 1 and continue unchanged over time.

Storage – No new storage—related to flood inundation process—would be anticipated with a project that minimize temporal disconnections due to diversions and withdrawals.

Data Collected to Adjust FFI and Monitor Connectivity, Fluvial Processes, and Project Effectiveness

The purpose of this section is to describe the project reporting that may be important for recalibrating P allocations and project credits awarded in the FFI planning tools for stream stability and storage crediting. This is not intended to be O&M monitoring, although, for projects involving the placement of structures, there may be overlaps and efficiencies gained by combining both types of monitoring. Crediting for several of the project groups described above could change based on project monitoring.

The following data would be used to adjust P award metrics and track connectivity in the FFI as described in the table below. Variables used to assess stream stability and storage:

1. Buffer viability and acres
2. Incision ratio
3. Floodplain acres
4. Sediment regime departure and channel evolution stage
5. Evidence of floodplain storage

Table 18. Proposed project reporting requirements by project type.

	Year 1	Year 5	Year 10	Every 10 years thereafter
Group 1 Lg. floodplain excavations	As built data to confirm initial credits.	Report on buffer viability and evidence of FP storage	Report on buffer maturity and evidence of FP storage	Report on five monitoring variables[12]
Group 2 Sm. floodplain excavations	As built data to confirm initial credits.	Report on buffer viability and evidence of FP storage	Report on buffer maturity and evidence of FP storage	Report on five monitoring variables
Group 3 Floodplain reconnection	As built data to confirm initial credits.	Report on buffer viability and evidence of FP storage	Report on buffer maturity and evidence of FP storage	Report on five monitoring variables
Group 4 Wood addition	As built data to confirm credits and possible removal credits.	Report on channel evolution and evidence of FP storage.	Is aggradation, FP reconnection and storage occurring warranting new vertical and storage credits?	Report on five monitoring variables and accrue further credits for new floodplain function
Group 5 Constraint removal	As built data to confirm credits and possible removal credits.	Where appropriate, report on new FP storage	Is new laterally accessible FP eligible for storage credit?	
Group 6 RC Easement	Easement documentation	Report on channel evolution stage and evidence of floodplain storage	If floodplain connectivity did not exist, has FP begun to reform	Report on five monitoring variables and accrue further credits for new floodplain storage
Group 7 RC bylaws and wetland protect	Bylaw[13] or easement documentation			
Group 8 Nat. vegetation buffers	As built data to confirm initial credits.	Report on buffer viability and evidence of FP storage	Report on buffer maturity.	

[12] Where floodplains have been restored, balanced erosion and deposition processes may be affecting channel evolution and equilibrium process in adjacent reaches, which could be documented for stream stability crediting.

[13] If municipality votes to un-adopt bylaw/zoning protections for river corridors, then floodplain connectivity scores would decrease and base loads would increase in the affected HUC 12s, putting more pressure on the need for other restoration and protection projects to achieve the TMDL reductions.

	Year 1	Year 5	Year 10	Every 10 years thereafter
Group 9 Stream crossings	As built data to confirm credits and possible vertical credits.		Has stream profile changed with new FP connectivity warranting new vertical and storage credits	
Group 10 Headcuts and gullies	As built data to confirm credits and possible vertical and/or removal credits.	Is grade control maintaining longitudinal connectivity (and credit)?	Is grade control maintaining longitudinal connectivity (and credit)?	
Group 11 Stormwater infiltration	As built info to confirm initial credits.			
Group 12 Water diversions	As built info to confirm initial credits.			

Appendix E. Incorporation of Process-Based Research into Connectivity-based P Allocations and Project Prioritization

Work is ongoing to integrate results of processed-based research from stream channels, floodplains and wetlands into the FFI framework for connectivity-based P allocations and project prioritization. At present, the mapping layers for each spatial data set will be overlain on FFI mapping layers to further guide and prioritize stream and floodplain reconnection projects.

Stream-based Sediment Regime Departure Types

Sediment regime departure (SRD) classifications (Underwood, 2021; Kline, 2009) are used to refine vertical connectivity P load allocations to stream reaches and to set priorities for projects designed to address floodplain (lateral and vertical) and stream (longitudinal/temporal) connectivity departures.

Table 19. Types of equilibrium and sediment regime departures within streams.

TR	Transport
DEP	Depositional
CEFD	Course Equilibrium Fine Deposition
CST	Confined Source and Transport
UST	Unconfined Source and Transport
FSTCD	Fine Source and Transport Course Deposition

- **Vertical connectivity**:
    - Incised streams (CST, UST, and FSTCD types), in lower valley settings, are assigned higher percentages of the vertical connectivity allocation (by reliance on departure scoring methods that consider Incision Ratio) due to the expected increased rate of fine sediment erosion from these reaches. Where vertical connectivity can be re-established in these SRD types, the channel evolution that would otherwise result in very high P loading, would be reduced significantly.
    - Stable, equilibrium reaches (IR = 1.0) get no vertical connectivity allocation.
    - Lowering the incision ratio by restoring floodplains increases the value of lateral meander, protection, and buffer connectivity scores and stream stability load reduction credits, e.g., a buffer planted on connected floodplain (IR =1.0) would get a greater buffer P load credit than a buffer planted on a moderate to severely incised stream (IR > 1.5).

- **Lateral connectivity (meander freedom space):**
  - Incised streams (UST and FSTCD types) are rated as higher priorities for projects that remove river corridor constraints to reestablish meander space. Where lateral connectivity is re-established, the unstable channel evolves in an unconstrained corridor resulting in channel slopes commensurate with least-erosive equilibrium conditions, and lower P loading rates.
  - Lateral connectivity projects are lower priorities in the river corridors of equilibrium and vertically stable reaches, recognizing that there may be some lateral constraint removal that is cost effective.
- **Protection of lateral connectivity**:
  - Protecting the processes that create meanders and floodplains, particularly along incised UST and FSTCD types, is assigned the highest priority. Where river corridors remain open and protected, channel evolution and vertical reconnection will result in stable channel slopes commensurate with least-erosive equilibrium conditions, greater flow and material storage, and lower P loading rates. CST streams, while incised, are moderate priorities for easement projects, because of the lower potential for sediment and P storage in steeper, confined settings.
  - Depositional, equilibrium and vertically stable reaches are lower priority for river corridor easements, however, there may be great value in the long-term protection of existing floodplain storage on the floodplains adjacent to larger DEP and CEFD streams that may be threatened by future stream or floodplain encroachment.
- **Laterally connected naturally vegetated buffers**:
  - High priority is assigned to naturally vegetated buffer restoration projects along depositional (DEP) and equilibrium streams (CEFD) where natural vegetation has a significant influence over the rate of natural channel migration.
  - Low priority is given to the restoration of a narrow (≤ 50’) buffer along incised and evolving SRD types, because, as a standalone practice, root depths would be insufficient to stabilize bank materials. Reestablishing natural vegetation within the entre river corridor of CST, UST, and FSTCD, however, would be a priority, as the river shore and floodplain forest communities would evolve with the incised stream over time.
- **Longitudinal Connectivity:**
  - Maintaining existing natural, longitudinal connectivity in any SRD type is important, because disruption of sediment and debris regimes may bring about erosion and

depositional processes that increase vertical disconnections and significantly effect stream stability and P loading.

    - High priority is given to the replacement of moderate to severely undersized stream crossings or the removal of derelict dams that result in significant upstream deposition and downstream bed erosion during floods. The depositional (DEP) SRD type is particularly sensitive to vertical instability due to breaks in longitudinal connectivity.

- **Temporal Connectivity**
    - Maintaining existing natural, temporal connectivity in any SRD type is important because disruption of the hydrologic regimes may bring about erosion and depositional processes that increase vertical disconnections and significantly effect stream stability and P loading.
    - High priority is given to the water quality certification of water withdrawals and diversions or the treatment of urban, road, or agricultural stormwater that result in significant changes in stream processes during floods. Smaller CEFD and DEP streams (DA ≤ 2 sq.ml.) are particularly sensitive to vertical instability due to changes in temporal connectivity.

Floodplain Deposition

Provisional results of research on floodplain sediment and P deposition during 2019 and 2020 (Diehl et al., 2021) indicate that the estimated pounds of P per acre per year varies across Lake Champlain Basin floodplains as a function of valley width, energy (i.e., ssp= specific stream power), and vertical connectivity (as measured by incision ratio (IR).

- Narrow-valley < 25 x W_{bkf} vs. Wide-valley > 25 x W_{bkf}
- Well-connected (IR<1.3) vs. moderately connected (1.3 < IR <1.9)
- Energy: Low SSP (<10 Watts/m^2; generally, gradients <0.001) vs. Med SSP (10-300 Watts/m^2).

Table 20. Estimated pounds of phosphorus deposited on floodplains per year as a function of valley width, energy (I.e., slope and discharge volumes), and vertical connectivity.

	Well-Connected		Moderately Connected	
	Low Energy	Medium Energy	Low Energy	Medium Energy
Narrow Valley	7.7	17.5	3.4	5.4

Wide Valley	14.6	26.2	13.1	18.5

Results from the 2021 season will be compiled in coming months to further define the range of expected sediment and P deposition and to help characterize the uncertainty in P deposition estimates across space and over time (and inform uncertainty in P credits allocated to floodplain storage). Statistical models generated in Diehl et al. (2021) will be updated with these new data and can be used to guide prioritization of floodplain reconnection sites and to optimize P attenuation in connected (or reconnected) floodplains.

Wetland Storage

P cycling in riparian wetlands is a complex process with many governing variables. Preliminary research findings from Roy and Wiegman (separate LCBP project) indicate that:

- Soluble reactive P (SRP) release can offset some of the P deposited in many riparian wetland sites, especially during winter/early spring floods when there is more plant litter subject to decomposition, and especially in sites where influent river SRP concentrations are relatively low to begin with.
- Across sites, preliminary data suggest decreasing SRP release from soils with time since farming.
- Certain soil metrics (e.g., Soil P Storage Capacity) predict soluble P loss risk from soils well.

Additional data collected in 2021 is presently being analyzed to build on the evidence base for proxies that can be used to estimate the SRP release risk for candidate floodplain restoration sites and compare this loss risk to anticipated deposition of sediment-bound P. These findings will be used, along with floodplain attenuation estimates above, to guide prioritization of floodplain reconnection sites to maximize P attenuation and minimize SRP release from connected (or reconnected) floodplains.

Appendix F. Example Calculations for Floodplain and Stream Connectivity Projects

The FFI Web Application and Users Guide will contain project planning worksheets that will walk the user through the following methods for calculating stream stability and storage credits. The core components of the method are described here.

In the FFI project planning worksheets, the user enters an ID for a stream subunit(s) in which they would like to calculate the possible connectivity and P load reduction credits for a project. The FFI will then populate fields describing the subunit dimensions, the TMDL P load allocation divided for lateral and vertical project debiting, existing connectivity acres and scores, and the and existing incision ratio.

Floodplain Connectivity

Beginning with the floodplain connectivity worksheet, the user enters the lateral and vertical connectivity acres and design incision ratio of their project. Proposed post-project acres and area weighted incision ratio are then calculated. In this example, the existing stream subunits are constrained (disconnected) both laterally and vertically. The FFI user has defined practice sets using acres of lateral and vertical connectivity change to derive connectivity credits that translate into P load reductions (lb/yr). In this example, the user has envisioned 3 sequential projects on the same reaches. The acres and incision ratio achieved through the first project are used as the existing conditions at the start of the planning for the 2nd project, and so forth.

FFI Project Crediting - Floodplain Connectivity
10/18/2021
Project Example

FFI supplied with input of subunit ID(s)
Input by User during planning exercise
FFI calculated in planning worksheet

Project Reach, Segment or Subunit		
ID	M13, M12B	
Area (Acres)	78.6	**RC(x) (acres)**
50' Buffer Area (Acres)	24	**BFR50 (acres)**
TMDL P Base Load Allocation	(kg/yr)	(lb/yr)
Total Connectivity Allocation	**71.2**	**156.9**
Lateral	**29.7**	**65.5**
Vertical	**41.5**	**91.4**

Web Map Variable Name:	**RC-connect (acres)**	**RP Acres**	**MP Acres**	**LP Acres**	**NP Acres**	**BFR50-woody-veg (acres)**	**IR**
	Connected Corridor (Acres)	Robust Protection (Acres)	Moderate Protection (Acres)	Low Protection (Acres)	No Protection (Acres)	Naturally Veg Buffer (Acres)	Incision Ratio
Existing	25	5	30	28.6	15	12	1.9

Project Area		
Project Number (Sequential)	1	
Area (Acres) with Vertical Change	3.1	
Remaining Connectivity Allocation		
TMDL P Base Load Allocation	(kg/yr)	(lb/yr)
Total Connectivity Allocation	**71.2**	**156.9**
Lateral	**29.7**	**65.5**
Vertical	**41.5**	**91.4**

Project Description: **Berm removal/floodplain lowering reconnecting 3.1 acres of floodplain, with easement, hard constraint removal, and bu**

	Connected Corridor (Acres)	Robust Protection (Acres)	Moderate Protection (Acres)	Low Protection (Acres)	No Protection (Acres)	Naturally Veg Buffer (Acres)	Incision Ratio
Existing	25	5	30	28.6	15	12	1.9
Project	3.1	3.1	0	0	-3.1	1	1.2
Proposed (Post-Project)	28.1	8.1	30	28.6	11.9	13	1.87

Project Area		
Project Number (Sequential)	2	
Area (Acres) with Vertical Change	3.1	
Remaining Connectivity Allocation		
	(kg/yr)	(lb/yr)
Total Connectivity Allocation	**68.1**	**150.1**
Lateral	**27.9**	**61.5**
Vertical	**40.2**	**88.6**

Project Description: **Berm removal/floodplain lowering reconnecting 3.1 acres of floodplain, with easement, hard constraint removal, and bu**

	Connected Corridor (Acres)	Robust Protection	Moderate Protection	Low Protection (Acres)	No Protection (Acres)	Naturally Veg Buffer (Acres)	Incision Ratio
Existing	28.1	8.1	30	28.6	11.9	13	1.87
Project	3.1	3.1	0	0	-3.1	1	1.2
Proposed (Post-Project)	31.2	11.2	30	28.6	8.8	14	1.84

Project Area		
Project Number (Sequential)	3	
Area (Acres) with Vertical Change	0	
Remaining Connectivity Allocation		
	(kg/yr)	(lb/yr)
Total Connectivity Allocation	**65.0**	**143.2**
Lateral	**26.1**	**57.4**
Vertical	**38.9**	**85.8**

Project Description: **Easement on 3.1 acres and 1.0 acre buffer.**

	Connected Corridor (Acres)	Robust Protection	Moderate Protection	Low Protection (Acres)	No Protection (Acres)	Naturally Veg Buffer (Acres)	Incision Ratio
Existing	31.2	11.2	30	28.6	8.8	14	1.84
Project	0	3.1	0	-3.1	0	1	
Proposed (Post-Project)	31.2	14.3	30	25.5	8.8	15	1.84

FFI then calculates the existing and proposed lateral and vertical connectivity and departure scores. Stream stability P load reduction credits are calculated by the FFI as a proportion of the base load equal to gains in connectivity within those areas.

In this example, the P load reduction for Projects 1 and 2 includes a stream stability credit because the practice sets include a vertical connectivity component. Project 3 creates an annual stream stability P load reduction credit for the lateral-only connectivity practices. An overall proposed project connectivity credit (lbs/yr) and subunit connectivity scores are also calculated and tracked within the FFI.

Variable		Subunit Existing Score	Subunit Existing Rank
Lateral-Meander Connectivity Score	RC %	31.8	Constrained
Lateral-Protection Score	PRT Score	34.5	Limited
Lateral-Buffer Score	BFR %	50.0	Limited
Lateral RC Connectivity Score	RC Score	35.5	Limited
Incision Ratio	Incision Ratio	1.90	High
Lateral-Vertical RC Connectivity (Attainment)	RC Score	18.7	Constrained
Lateral-Vertical RC Connectivity Departure Sc	RC Score	81.3	N/A

Max. Potential Attainment Score Given IR	52.6
Min. Potential Departure Score Given IR	47.4
Difference from Existing Departure	34.0
% of Existing Departure	42%

Variable		Subunit Existing Score	Subunit Existing Rank	Subunit Proposed 1 Score	Subunit Proposed 1 Rank
Lateral-Meander Connectivity Score	RC %	31.8	Constrained	35.8	Low
Lateral-Protection Score	PRT Score	34.5	Limited	38.5	Limited
Lateral-Buffer Score	BFR %	50.0	Limited	54.2	Moderate
Lateral RC Connectivity Score	RC Score	35.5	Limited	39.5	Limited
Incision Ratio	Incision Ratio	1.90	High	1.87	High
Lateral-Vertical RC Connectivity (Attainment)	RC Score	18.7	Constrained	21.1	Constrained
Lateral-Vertical RC Connectivity Departure Sc	RC Score	81.3	N/A	78.9	N/A

Proposed Project 1 Practice Set Credits

Proposed Connectivity Credit (Score):	2.4
oposed Lateral Connectivity Credit (% of EX):	6%
posed Vertical Connectivity Credit (% of EX):	3%
Lateral P Reduction Credit (kg/yr):	1.8
Vertical P Reduction Credit (kg/yr):	1.3
P Reduction Credit (kg/yr):	**3.1**
P Reduction Credit (lb/yr):	**6.8**

Existing Subunit Connectivity Score	18.7
Proposed Project Connectivity Credit	**2.4**
Proposed Subunit Conectivity Score	21.1

Variable		Subunit Existing Score	Subunit Existing Rank	Subunit Proposed 2 Score	Subunit Proposed 2 Rank
Lateral-Meander Connectivity Score	RC %	35.8	Low	39.7	Low
Lateral-Protection Score	PRT Score	38.5	Limited	42.4	Limited
Lateral-Buffer Score	BFR %	54.2	Moderate	58.3	Moderate
Lateral RC Connectivity Score	RC Score	39.5	Limited	43.4	Limited
Incision Ratio	Incision Ratio	1.87	High	1.84	High
Lateral-Vertical RC Connectivity (Attainment)	RC Score	21.1	Constrained	23.6	Constrained
Lateral-Vertical RC Connectivity Departure Sc	RC Score	78.9	N/A	76.4	N/A

Proposed Project 2 Practice Set Credits

Proposed Connectivity Credit (Score):	2.5
oposed Lateral Connectivity Credit (% of EX):	7%
posed Vertical Connectivity Credit (% of EX):	3%
Lateral P Reduction Credit (kg/yr):	1.8
Vertical P Reduction Credit (kg/yr):	1.3
P Reduction Credit (kg/yr):	**3.1**
P Reduction Credit (lb/yr):	**6.8**

Existing Subunit Connectivity Score	21.1
Proposed Project Connectivity Credit	**2.5**
Proposed Subunit Conectivity Score	23.6

Variable		Subunit Existing Score	Subunit Existing Rank	Subunit Proposed 2 Score	Subunit Proposed 2 Rank
Lateral-Meander Connectivity Score	RC %	39.7	Low	39.7	Low
Lateral-Protection Score	PRT Score	42.4	Limited	45.4	Limited
Lateral-Buffer Score	BFR %	58.3	Moderate	62.5	Moderate
Lateral RC Connectivity Score	RC Score	43.4	Limited	45.1	Limited
Incision Ratio	Incision Ratio	1.84	High	1.84	High
Lateral-Vertical RC Connectivity (Attainment)	RC Score	23.6	Constrained	24.5	Constrained
Lateral-Vertical RC Connectivity Departure Sc	RC Score	76.4	N/A	75.5	N/A

Proposed Project 2 Practice Set Credits

Proposed Connectivity Credit (Score):	0.9
oposed Lateral Connectivity Credit (% of EX):	3%
posed Vertical Connectivity Credit (% of EX):	0%
Lateral P Reduction Credit (kg/yr):	0.8
Vertical P Reduction Credit (kg/yr):	0.0
P Reduction Credit (kg/yr):	**0.8**
P Reduction Credit (lb/yr):	**1.7**

Existing Subunit Connectivity Score	23.6
Proposed Project Connectivity Credit	**0.9**
Proposed Subunit Conectivity Score	24.5

TAL CREDIT (kg/	**7.0**
TAL CREDIT (lb/	**15.4**

Stream Connectivity

In the stream connectivity worksheet, the FFI supplies departure scores and the user enters the longitudinal and temporal credits that would be gained by their proposed project. Post-project departure scores are then calculated. In this example, the change in incision ratio, achieved by floodplain excavation and berm removal, is the only project component awarded stream connectivity credits.

Stream stability P load reduction credits are calculated by the FFI as a proportion of the base load equal to gains in stream connectivity within project reaches. The stream connectivity worksheet shows only the results of Project 1 from the sequence of projects calculated in the above section explaining the floodplain connectivity worksheet.

FFI Project Crediting - Stream Connectivity
9/20/2021
Case 4 - Stream Connectivity Project

Project reach, segment or subunit		
ID	M13, M12B	
TMDL P Base Load Allocation	(kg/yr)	(lb/yr)
Stream	5.21	11.49
Longitudinal	4.10	9.04
Temp-Structures	0.72	1.59
Temp-Dev LU	0.20	0.44
Temp-Ag LU	0.20	0.44
Area (Acres)	78.6	
Area (Acres) with Vertical Change	3.1	
Percent Area with Vertical Change	3.9%	

Connectivity project: Change in IR with floodplain restoration

	Longitudinal Deductions (Structures and IR)	Temporal Deductions (Structures and IR)	Temp-Dev LU HUC12 roads/dev LU (mi/mi$_2$)	Temp-Ag LU HUC12 ag LU/DA (%)_Tile	Incision Ratio
Existing	-40	-60	5	50	1.9
Project	0	0	0	0	1.2
IR	0.8	0.3			
Proposed (Post-Project)	-39.2	-59.7	5	50	1.2
Maximum Values in Basin			10	80	

Will the project disconnect tile drains or ditches in an agricultural setting?	no
Land Use Change Area (Acres)	0.0
Is the incision ratio changing?	yes

	Longitudinal Score	Temporal Deductions Score	Temporal Roads Score	Temporal Ag Score
Existing	60.0	40.0	50.0	37.5
Proposed (Post-Project)	60.8	40.3	50.0	37.5

	Longitudinal	Temporal
Existing IR deduction	-20.0	-8.0
Proposed IR deduction	0.0	0.0
Area Weighted IR deduction	-19.2	-7.7
Change in score	0.8	0.3

	Longitudinal	Temporal	Stream
Existing Connectivity Score:	60	42.3	52.90
Existing Connectivity Departure:	40	57.8	47.1
Proposed Connectivity Score:	60.8	42.4	53.42
Proposed Connectivity Departure:	39.2	57.6	46.6
Proposed Connectivity Credit (Score):			0.52
Proposed Connectivity Credit (% of EX):			1.1%
Stream Connectivity P Credit (kg/yr):			**0.058**
Stream Connectivity P Credit (lb/yr):			**0.128**

Incision	Incision Ratio[1]	Longitudinal Score Deduction	Temporal Score Deduction
Minor	IR < 1.3	0	0
Moderate	1.3 ≤ IR < 1.5	-10	-5
High	1.5 ≤ IR < 2.0	-20	-8
Severe	IR > 2.0	-30	-10

Storage

In the Storage worksheet, the user need only enter the existing and proposed floodplain connectivity of the project acres. In this example, the 3.1 acres of floodplain has a low existing lateral-vertical connectivity, but would have a high connectivity with the removal of hard constraints and berm, new robust protections, buffer planting, and excavation to achieve an incision ratio of 1.2.

FFI Project Crediting - P Storage
8/3/2021

Project reach, segment or subunit	
ID	M13, M12B
Connectivity project	Floodplain restoration
Project Area (acres)	3.1
Existing connectivity in Project Area	Low
Proposed connectivity in Project Area	High

Estimated TP Storage Credit (lb/yr)			
Year 1	**Year 5**	**Year 20**	**Year 40**
62	31	31	31

Default TP Storage Credits (lb/ac/yr)*		
Low to High	**Low to Moderate**	**Moderate to High**
20	**15**	**10**
10	**7**	**5**

*To be updated by project specific measurements or future research.

The storage credit will be assigned to the load and waste load sectors located upstream of a floodplain storage site and distributed based on the contribution of a) regulated vs. non-regulated loads, and b) the percent sector contribution to the base load as reported in the TMDL for each Lake Champlain subbasin (EPA, 2016).

Crediting Summary

Each project planning exercise will generate a project crediting summary that includes floodplain and stream connectivity credits from the stream stability allocation, storage credits from upstream load and waste load sector allocations (including the stream stability sector), and totals for Year 1 and subsequent years.

FFI Project Crediting - Summary
12/20/2021
Project: Lateral/vertical on the same footprint + longitudinal/temporal

Project Name	Dog River Floodplain Restoration Project
River	Dog River and Union Brook
Town	Northfield, VT
Location	Water Street
Project reach, segment or subunit ID(s)	**M13, M12B**
Project reach, segment or subunit(s) Area (acres)	78.6
Connectivity project components	Area (acres)
Constraint (house) removal	3.1
Floodplain lowering / berm removal	3.1
Buffer planting	3.1
River Corridor easement	3.1

ESTIMATED PHOSPHORUS CREDITING

	Year 1	Years 2+
Floodplain (lb/yr)	6.8	6.8
Stream (lb/yr)	0.1	0.1
Storage (lb/yr)	62.0	31.0
TOTAL	**69.0**	**38.0**

Appendix G. Stream Stability P Load Reduction Credits for Common Stream and Floodplain Connectivity Projects

Median values for P load reduction credits for the stream stability sector were estimated using the FFI Phase 1 dataset for floodplain and stream connectivity for streams with a watershed area of 2 square miles or greater (Table 19). For each simulated project, the data were filtered to select those subunits meeting the required minimum conditions for the practice (Table 20).

The simulated typical Vermont projects represent a range of potential values across the Lake Champlain Basin and vary based on the stream or floodplain's degree of departure from target conditions and the stream stability load allocation to the HUC12 watershed in which the project is located (Table 19). Beyond this initial estimate, actual crediting for individual projects will be calculated and tracked within the final FFI web application during project planning and implementation.

In direct drainage watersheds where the stream stability loads are incorporated into the loads of other sectors (i.e., no direct load allocation has been made to the stream stability sector), the North and Lake Champlain simulation median credits provide appropriate values for crediting stream and floodplain connectivity projects, given their similarities in land use and natural settings to direct drainages (i.e., topography, soils, precipitation patterns). Proposed P-credit values for the direct drainage watersheds are presented in Table 21.

Detailed simulation results, including the number of simulated projects and mean and median P load reductions, are presented in Table 22.

Table 21. Median P load reduction credits for common stream and floodplain connectivity projects.

Project Type (Appendix D)	Simulated Project	Median P Reduction Credit	P Credit Units
1A, 3	Floodplain Restoration with Buffer Revegetation	1.6	lb/ac/yr
1A, 3	Floodplain Restoration with Buffer Revegetation and Easement	2.1	lb/ac/yr
1B	Large/medium dam removal with floodplain restoration	2.0	lb/ac/yr
2	Small/medium intact ROR or breached dam removal with floodplain restoration	2.1	lb/ac/yr
4	Wood addition in 1st and 2nd order streams with vertical reconnection	1.7	lb/ac/yr
4	Wood addition in 3rd and 4th order streams with vertical reconnection	0.6	lb/ac/yr
5	Remove hard constraint	1.1	lb/ac/yr
6	Passive Restoration - Easement and Buffer Revegetation	0.7	lb/ac/yr
7	Adopt Corridor Bylaws	0.2	lb/ac/yr
8A	Buffer Revegetation	0.6	lb/ac/yr
9B	Replace Culverts - Undersized with Shallow Slope	2.0	lb/culvert/yr
10	Stabilize Gully on Perennial Stream	2.6	lb/project/yr

Table 22. Criteria for simulations of stream and floodplain connectivity P load reduction credits.

Project Type (Appendix D)	Simulated Project	Simulated Project Components	Subset Filtering Criteria
1A, 3	Floodplain Restoration with Buffer Revegetation	1/3 acre buffer	IR > 1.3
		1 acre floodplain lowering (IR = 1)	≥ 1/3 acre unvegetated
			≥ 1 acre Unconstrained
	Floodplain Restoration with Buffer Revegetation and Easement	1/3 acre buffer	IR > 1.3
		1 acre easement	≥ 1/3 acre unvegetated
		1 acre floodplain lowering (IR = 1)	≥ 1 acre without Robust Protection
			≥ 1 acre Unconstrained
1B	Large/medium dam removal with floodplain restoration	Remove large or medium dam	LARGE_FLOOD_DAM
		Normalize by impoundment area	LARGE_PEAKING_DAM
		Add median floodplain restoration with buffer revegetation credit	LARGE_ROR_DAM
			MED_PEAKING_DAM
2	Small/medium intact ROR or breached dam removal with floodplain restoration	Remove small or medium dam	MED_ROR_DAM
		Normalize by impoundment area	MED_BREACHED_DAM
		Add median floodplain restoration with buffer revegetation credit	SMALL_ROR_DAM
			SMALL_BREACHED_DAM
4	Wood addition in 1st and 2nd order streams with vertical reconnection	1 acre floodplain reconnection (IR =1)	IR > 1.3
			Stream Order 1-2
			Subunit Area ≥ 1 acre
4	Wood addition in 3rd and 4th order streams with vertical reconnection	1 acre 50% IR improvement	IR > 1.3
			Stream Order 3-4
			Subunit Area ≥ 1 acre
5	Remove hard constraint	0.5 acre constraint removal	≥ 0.5 acre Constrained
6	Passive Restoration - Easement and Buffer Revegetation	1/3 acre buffer	IR 1.2 - 1.8
		1 acre easement (robust protection)	≥ 1 acre unvegetated
			Non-Ag Lateral Connectivity ≥ 90%
			≥ 1 acre without Robust or Moderate Protection
7	Adopt Corridor Bylaws	Low or No Protection Converted to Moderate Protection	> 0 acre with Low or No Protection
8A	Buffer Revegetation	1 ac buffer	IR 1.2 - 1.8
			≥ 1 acre unvegetated
			Non-Ag Lateral Connectivity ≥ 90%

			≥ 1 acre without Robust or Moderate Protection
9B	Replace Culverts - Undersized with Shallow Slope	Convert to Bankfull Structure	Culvert Type = <50% BKF Width, Shallow Slope
10	Stabilize Gully on Perennial Stream	Add 30 to Long and Temp Deductions	Number of Gullies ≥ 1

Table 23. Estimated Median P load reduction credits for simulated stream and floodplain connectivity projects.

Project Type (Appendix D)	Simulated Project	Northern Lake Champlain	Southern Lake Champlain	P Credit Units
1A, 3	Floodplain Restoration with Buffer Revegetation	0.7	1.2	lb/ac/yr
1A, 3	Floodplain Restoration with Buffer Revegetation and Easement	0.9	1.5	lb/ac/yr
1B	Large/medium dam removal with floodplain restoration	0.7	1.5	lb/ac/yr
2	Small/medium intact ROR or breached dam removal with floodplain restoration	0.8	1.2	lb/ac/yr
4	Wood addition in 1st and 2nd order streams with vertical reconnection	1.2	2.8	lb/ac/yr
4	Wood addition in 3rd and 4th order streams with vertical reconnection	0.3	0.5	lb/ac/yr
5	Remove hard constraint	0.5	1.0	lb/ac/yr
6	Passive Restoration - Easement and Buffer Revegetation	0.4	0.8	lb/ac/yr
7	Adopt Corridor Bylaws	0.2	0.3	lb/ac/yr
8A	Buffer Revegetation	0.3	0.8	lb/ac/yr
9B	Replace Culverts - Undersized with Shallow Slope	1.4	2.7	lb/culvert/yr
10	Stabilize Gully on Perennial Stream	1.1	4.2	lb/project/yr

Table 24. Complete results summary for simulated stream and floodplain connectivity projects.

Project Type (Appendix B)	Simulated Project	Basin Plan:	Lamoille	Missisquoi	Northern Lake Champlain	Otter Creek-Little Otter Creek-Lewis Creek	Southern Lake Champlain	Winooski	Overall
1A, 3	**Floodplain Restoration with Buffer Revegetation (lb/ac/yr)**	**mean**	0.5	2.9	1.1	1.4	1.4	2.9	1.9
		median	**0.4**	**2.9**	**0.7**	**1.4**	**1.2**	**2.7**	**1.6**
		n	*496*	*338*	*88*	*506*	*134*	*663*	*2225*
	Floodplain Restoration with Buffer Revegetation and Easement (lb/ac/yr)	**mean**	0.6	3.9	1.5	1.9	1.9	3.8	2.5
		median	**0.6**	**3.8**	**0.9**	**1.9**	**1.5**	**3.4**	**2.1**
		n	*481*	*335*	*87*	*495*	*133*	*648*	*2179*
1B	**Large/medium dam removal with floodplain restoration (lb/ac/yr)**	**mean**	0.7	3.5	0.7	2.6	1.5	3.1	2.2
		median	**0.6**	**3.3**	**0.7**	**2.0**	**1.5**	**3.0**	**2.0**
		n	*4*	*5*	*1*	*11*	*2*	*14*	*37*
2	**Small/medium intact ROR or breached dam removal with floodplain restoration (lb/ac/yr)**	**mean**	0.8	4.7	0.8	2.4	1.5	12.7	6.4
		median	**0.4**	**3.3**	**0.8**	**1.5**	**1.2**	**4.7**	**2.1**
		n	*8*	*10*	*3*	*18*	*10*	*38*	*87*
4	**Wood addition in 1st and 2nd order streams (lb/ac/yr)**	**mean**	0.4	1.9	1.2	1.3	2.5	2.3	1.7
		median	**0.3**	**1.8**	**1.2**	**1.3**	**2.8**	**1.9**	**1.7**
		n	*28*	*68*	*6*	*45*	*16*	*45*	*208*
4	**Wood addition in 3rd and 4th order streams (lb/ac/yr)**	**mean**	0.2	1.2	0.4	0.6	0.6	1.3	0.8
		median	**0.2**	**1.1**	**0.3**	**0.5**	**0.5**	**1.1**	**0.6**
		n	*485*	*334*	*108*	*439*	*157*	*597*	*2120*
5	**Remove hard constraint (lb/ac/yr)**	**mean**	0.4	2.3	0.9	1.2	1.3	2.4	1.5
		median	**0.3**	**2.2**	**0.5**	**1.0**	**1.0**	**2.1**	**1.1**
		n	*1215*	*994*	*309*	*1616*	*448*	*1557*	*6139*
6		**mean**	0.3	1.8	0.8	0.8	1.0	2.1	0.9
		median	**0.3**	**1.9**	**0.4**	**0.8**	**0.8**	**2.1**	**0.7**

Project Type (Appendix B)	Simulated Project	Basin Plan:	Lamoille	Missisquoi	Northern Lake Champlain	Otter Creek-Little Otter Creek-Lewis Creek	Southern Lake Champlain	Winooski	Overall
	Passive Restoration - Easement and Buffer Revegetation (lb/ac/yr)	**n**	*197*	*123*	*18*	*194*	*57*	*43*	*635*
7	**Adopt Corridor Bylaws (lb/ac/yr)**	**mean**	0.1	0.5	0.3	0.3	0.4	0.7	0.4
		median	**0.1**	**0.5**	**0.2**	**0.3**	**0.3**	**0.7**	**0.2**
		n	*971*	*595*	*137*	*1124*	*313*	*562*	*3702*
8A	**Buffer Revegetation (lb/ac/yr)**	**mean**	0.3	1.9	0.6	0.9	0.9	2.1	1.0
		median	**0.2**	**1.8**	**0.3**	**0.8**	**0.8**	**2.0**	**0.6**
		n	*197*	*123*	*18*	*194*	*57*	*43*	*635*
9B	**Replace Culverts - Undersized with Shallow Slope (lb/culvert/yr)**	**mean**	1.3	7.5	1.4	4.2	2.7	5.7	4.3
		median	**0.5**	**3.6**	**0.8**	**2.2**	**1.4**	**5.7**	**2.0**
		n	*32*	*56*	*31*	*69*	*27*	*43*	*258*
10	**Stabilize Gully on Perennial Stream (lb/project/yr)**	**mean**	1.6	7.5	1.0	0.2	4.8	1.8	1.5
		median	**0.7**	**6.9**	**1.1**	**0.2**	**4.2**	**1.2**	**2.6**
		n	*5*	*6*	*7*	*2*	*6*	*25*	*51*

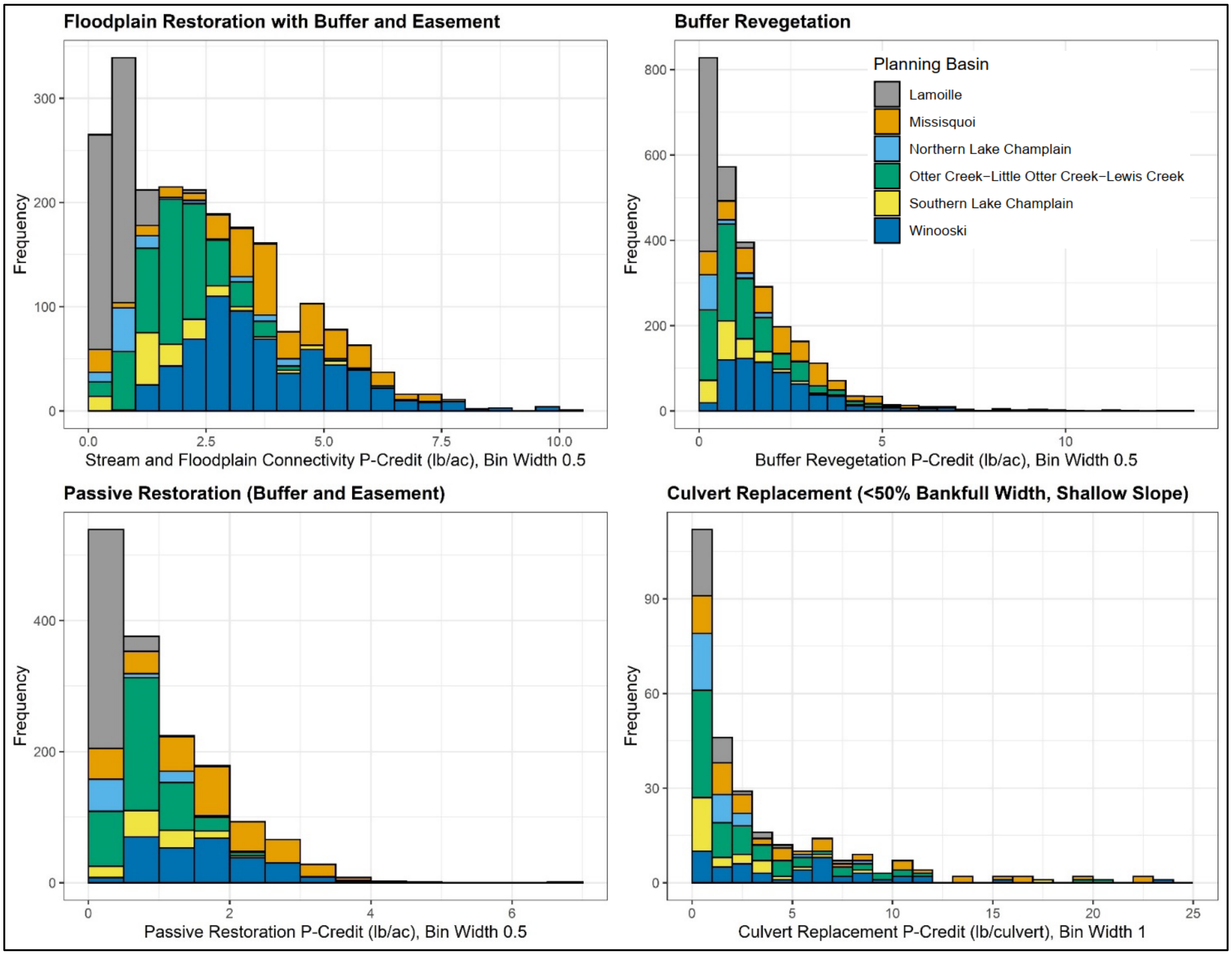
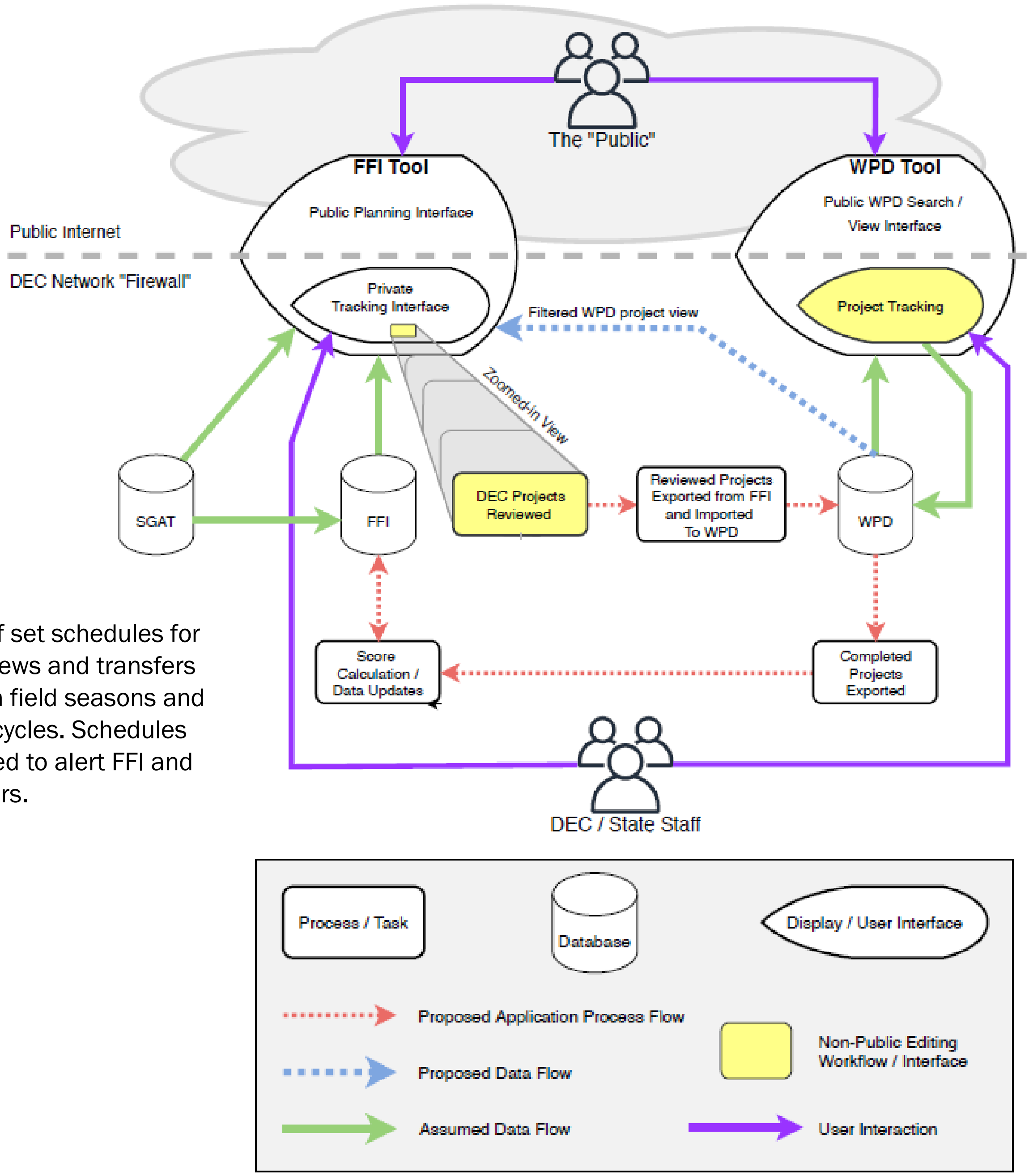


Figure 18. Sample histograms of P-credits for simulated stream and floodplain connectivity projects.

Appendix H. Data Inputs, Outputs, and Tracking Within and Between FFI and WPD

Data inputs, outputs, and tracking within and between DEC's FFI database and Watershed Projects Database (WPD) are outlined and explained here with the following set of graphics. Fundamentally, the FFI is storing and tracking reach-based connectivity scores (i.e., acres and connectivity components) and P allocations at the stream reach/subunit and HUC 12 scales. The WPD is tracking project-specific connectivity and P credits. Potential projects generated in FFI planning tools with connectivity and P load reduction credits (i.e., channel stability and floodplain storage credits) are exported out of the FFI and imported into the WPD where they move from project development to design and implementation. Once a project is complete, the as-built subunit- or reach-based connectivity acres/scores would be revised in the FFI, and HUC 12 stream stability P base load allocations would be updated in the FFI to reset connectivity and reach/subunit P allocations.

Project "dots," placed on FFI mapped stream subunits and reaches, would allow the user to see where projects are underway or completed. By clicking on the dot, the FFI user would see a brief project description and a link giving them a window to the project data stored and tracked in the WPD.



DEC staff set schedules for data reviews and transfers based on field seasons and funding cycles. Schedules are posted to alert FFI and WPD users.

Figure 19. Data flow between FFI tool and the Watershed Projects Database.

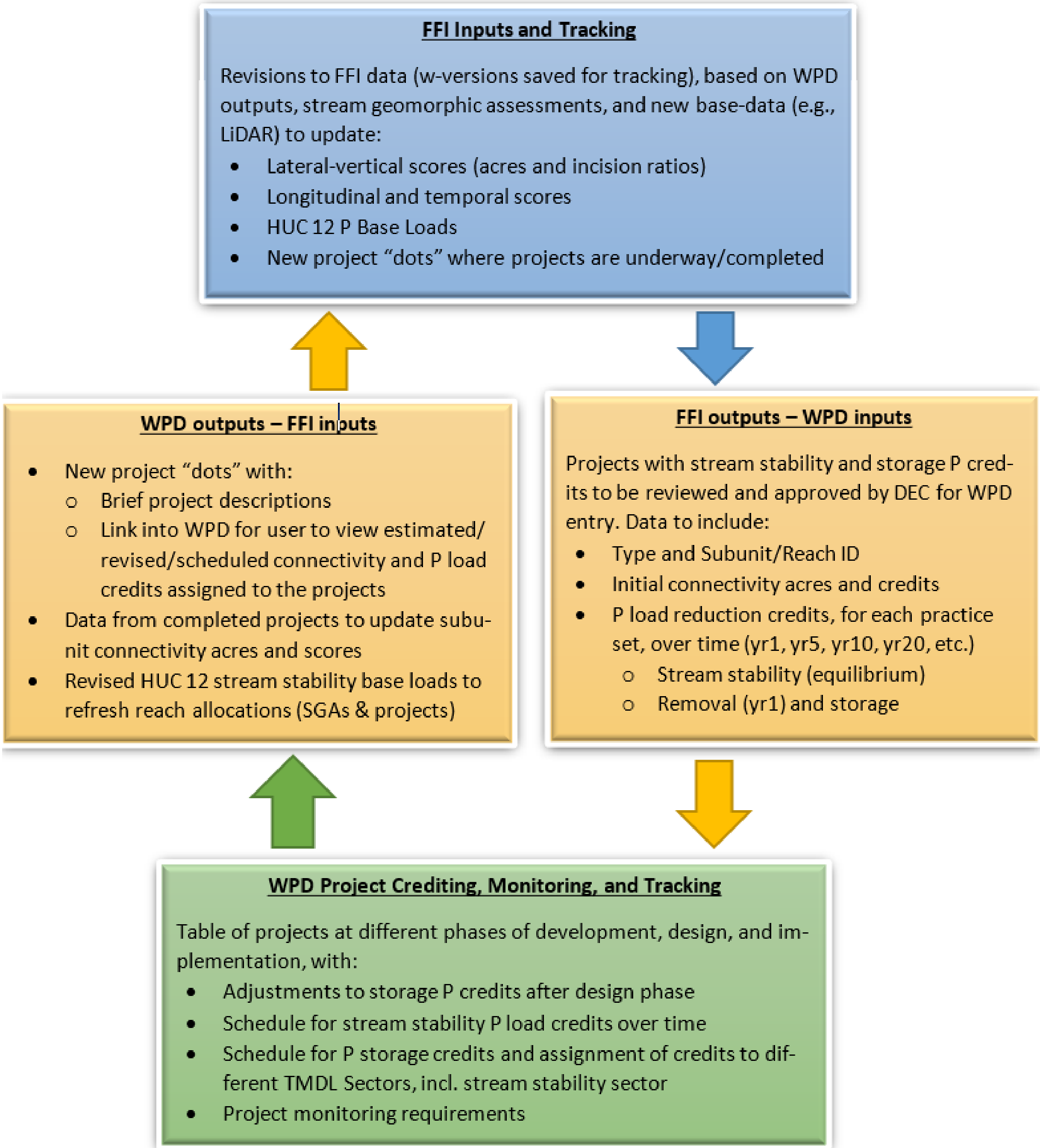


Figure 20. Types of data that will flow between FFI tool and the Watershed Projects Database.

DEC staff are the gatekeepers of data flow between the FFI and the WPD. They would determine schedules for outputs/inputs between the two tracking systems, perhaps influenced by scheduled rounds of project funding and reporting and the field seasons established for monitoring and assessment. The key to understanding the following outline is that the FFI tracks stream reach/subunit P allocations and connectivity scores, and the WPD tracks project P and connectivity credits.

FFI Inputs and Tracking

Annual Revisions (versions of FFI data saved for tracking and reporting), based on WPD outputs (see below), stream geomorphic assessments, or new base data (e.g., new LiDAR).

- Lateral constraint acres
- Protected river corridor acres
- Natural riparian buffer acres
- Subunit incision ratio/acres
- Longitudinal disconnections/credits
- Temporal disconnections/credits
- HUC 12 Base Loads
- New project "dots" to view data in WPD

Note that stream geomorphic assessments are separate from project monitoring and will likely document significant changes in connectivity over time at the reach scale rather than the site-scale. An example would be assessments that take place after a flood event that result in channel evolution and changes in stream and floodplain connectivity. Documented reach-scale changes in connectivity are entered into the FFI following the SGA and the resulting changes in stream stability base loads are noted and tracked by DEC as natural channel evolution credits (i.e., programmatic vs. project-related base load reductions).

FFI outputs – WPD inputs

Project proponents (e.g., project grantees) would obtain from the FFI the stream stability and storage P credits for review and approval by DEC for WPD entry

- Project location/Subunit ID
- Project type (including which types of connectivity restored/protected)
- Connectivity acres and scores for:

    - Each practice set
    - Project as a whole
- Provisional P load reduction credits, for each practice set, over time (yr1, yr5, yr10, 20, 30), for
    - Stream stability (equilibrium)
    - Floodplain/wetland Storage

WPD Project Crediting, Monitoring, and Tracking

Table of projects at different phases of development, design, implementation, and post-implementation performance, with

- Adjustments to storage P credits after design and implementation phase using more precise field-based surveys of floodplain/wetland characteristics (affecting estimated storage credit).
- Schedule for assignment of P storage credits to different TMDL Sectors (provisionally output from FFI, but likely to change through project development, design and implementation)
    - Developed lands (with breakout to VTrans, others?)
    - Agricultural lands
    - Forest lands
    - Stream stability
- Schedule for stream stability P load credits (less likely to change from the FFI output). The administration of the schedule could take one of these two forms:
    - Pre-awarded and retracted if design specifications and monitored targets are not met, or
    - Awarded on scheduled years as determined with monitoring
- Project monitoring requirements to determine credit awards/retainment over time

<u>WPD outputs – FFI inputs (circling back around to the top)</u>

- New project "dots" for projects that have been awarded funding with:
    - Brief project descriptions indicating practice type and types of connectivity restored/protected

    - Link into WPD for user to view more detail including project phase and the estimated/revised/scheduled connectivity and P load credits assigned to the project
- Data from completed projects and monitoring reports that justify updates to subunit or reach connectivity acres and scores in the FFI
- Revised HUC 12 P base loads to refresh subunit (Lateral-Vertical) and reach (Longitudinal-Temporal) allocations