Standard Operating Procedures for Tracking & Accounting of Stormwater Permit Programs: Municipal Roads General Permit (MRGP)

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Summary of MRGP Tracking & Accounting Methods

Project Type	Definition and Minimum Standards to Quantify Pollutant Reductions	Data Required to Quantify Pollutant Reductions	Total Phosphorus Load Reduction Efficiency (%)	References for P Reduction Efficiency
Road Erosion Remediation on Gravel and Paved Open Drainage (Uncurbed) Roads	Installation of a suite of practices to correct road related erosion problems for gravel and paved roads and road drainage culverts. Practices may include drainage ditch installation and upgrades, turnouts, removal of high road shoulders, and stabilization of drainage culverts.	Road segment ID Road type (paved, unpaved) Hydrologic connectivity Project length Municipal Roads General Permit compliance status before and after implementation	Not → partially compliant: 40% Partially → fully compliant: 40% Not → fully compliant 80%	Adapted from Wemple (2013)
Road Erosion Remediation on Class 4 Roads	Correction of gully erosion on Class 4 road surface and shoulder.	Road segment ID Hydrologic connectivity Project length Volume of gully erosion Municipal Roads General Permit compliance status before and after implementation	Average 30% (depends on erosion volume and road slope)	Adapted from Wemple (2013)
Catch Basin Outlet Stabilization on Paved, Curbed Roads	Correction of erosion at catch basin outlet by stabilizing flow path from outlet to surface waters.	Catch basin outlet ID Volume of erosion Municipal Roads General Permit compliance status before and after implementation	Calculated based on volume of erosion prior to stabilization	USDA (2002)

I. Introduction

Roads are considered a critical source area for phosphorus (US EPA 2016) nonpoint source pollution (US EPA 2016). The Municipal Roads General Permit (MRGP) is a requirement of the Vermont Clean Water Act (Act 64 of 2015) and the Vermont Lake Champlain Total Maximum Daily Load (TMDL) Accountability Framework (US EPA 2016).[1] The MRGP is intended to achieve significant reductions in stormwater-related erosion from paved and unpaved municipal roads. Municipalities are required to develop and implement a customized, multi-year plan to stabilize their road drainage system in order to achieve progress towards meeting TMDLs and other water quality restoration goals. Actions will include bringing road drainage systems up to maintenance standards and performing additional corrective measures to reduce erosion.

The Vermont Lake Champlain TMDL Accountability Framework contains the requirement for the State of Vermont to develop a comprehensive TMDL implementation tracking and reporting system. This document outlines the methods currently used by the State to track and account for nutrient reductions achieved through roads-related projects associated with the MRGP and road standards required by the Municipal Separate Storm Sewer System (MS4) permit.

As monitoring progress towards achieving the Lake Champlain and Lake Memphremagog TMDL phosphorus reduction targets is a key priority, DEC is working to develop tracking and accounting methods for all possible road improvement practices resulting in nutrient reductions. The Clean Water Service Delivery Act (Act 76 of 2019) requires addressing gaps and publishing methods to estimate phosphorus reductions for clean water projects implemented in Lake Champlain and Lake Memphremagog basins by November 2021. This SOP will be updated as new tracking and accounting methods are developed.

II. MRGP Standards & Definitions

Municipal roads in Vermont have been divided into 100-meter (328 feet) road segments with unique identification numbers using a geographic information system (GIS) analysis (Stone 2014).[2] Municipal road segments are classified as "hydrologically connected" or "not connected" using field surveys and GIS analyses.[3] When assessments occur in the field, a road segment's classification may be updated based on the conditions observed.

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[1] For more information on the MRGP, please visit: https://dec.vermont.gov/watershed/stormwater/permit-information-applications-fees/municipal-roads-program

[2] A map layer titled "Hydrologically Connected Road Segments (MRGP)" can be displayed on the Natural Resource Atlas under the "Stormwater" layer. All roads-related data can also be displayed on the Atlas under the Municipal Roads Theme from the drop-down menu. The Atlas can be accessed at: http://anrmaps.vermont.gov/websites/anra5/.

[3] For more information on the methods used to classify municipal roads, please visit: https://dec.vermont.gov/sites/dec/files/wsm/stormwater/docs/Permitinformation/MunicipalRoads/sw_MethodologyForDeterminingMunicipalRoadsHydrologicConnectivity_GIS-DerivedProximityAnalysis.pdf

Under the MRGP, all "hydrologically connected" road segments are required to be assessed for compliance with road standards (see Appendix A for road standards). A "hydrologically connected" road segment meets one of the following criteria:

1. Municipal road segment within 100' of a perennial or intermittent stream, lake, pond, wetland, or defined channel
2. Municipal road segment that bisects water or a defined channel
3. Municipal road segment is uphill from, and drains to, a municipal road that bisects water or a defined channel.

Municipal roads are classified into three general categories under the MRGP:

i. Paved and unpaved roads with ditches (Class 1-3)
ii. Paved roads with curbs and catch basins
iii. Class 4 roads

Each road category has specific standards under the MRGP (Appendix A). For Class 4 roads and paved/unpaved roads with ditches, MRGP standards are based on the conditions on the road segment. The standards for paved roads with curbs and catch basin, however, are based on the condition of the catch basin outlet rather than the road segment.[4]

The degree to which each road segment adheres to the MRGP standards determines its compliance score. Compliance scores fall in to three categories: *Does Not Meet* (DNM), *Partially Meets* (PM), or *Fully Meets* (FM) standard. The specific definition of DNM, PM, and FM varies based on the road type scoring (Appendix A). Compliance scores are the basis for the MRGP accounting methodologies outlined below.

III. MRGP Tracking Methodologies

a. Data Sources

DEC obtains MRGP road condition data through several mechanisms (Table 1):

1. Road Erosion Inventories (REIs) assess the compliance scores of all hydrologically connected road segments within a municipality. They are required to be completed and submitted to DEC by December 31, 2020. REIs will be required during each MRGP five-year permit cycle. REI data can be submitted to DEC in spreadsheet format or via DEC's MRGP mobile application, Survey123. To collect REI data in the field, ArcGIS Collector

[4] A map layer of "Hydrologically Connected Outlets" can be displayed on the Natural Resource Atlas under the "Stormwater" layer or Municipal Roads Theme. This allows DEC and municipalities to connect the compliance scores of each outlet to the contributing segments. Data for Chittenden County are still under development. The Atlas can be accessed at: http://anrmaps.vermont.gov/websites/anra5/.

and Survey123 are used. ArcGIS Collector is used to locate the segment or outlet for inventory, then Survey123 is used to complete the assessment of the road segment.[5]

2. Municipal Roads Grants-in-Aid (GIA) Program provides funding for municipalities to comply with the MRGP. Funding is directed to road improvement project construction on hydrologically connected municipal road segments that do not meet or partially meet MRGP standards. All work must result in bringing those segments into full compliance with the MRGP. Grantees are required to submit data collected on the pre-construction condition and the post-construction condition of the road for each segment improved under the program to DEC annually. The administration of the GIA Program will be transferred from DEC to the Vermont Agency of Transportation (VTrans) in July 2020.

3. VTrans grant programs provide funding to towns to inventory and improve roads through the VTrans Better Roads Program, Transportation Alternatives Program, and Municipal Highway and Stormwater Mitigation Program. VTrans submits the results of their funding programs to DEC annually.

Table 1. Data tracked to calculate phosphorus reductions from road improvement projects.

Data Tracked	Definition
Road segment ID	Municipal road segmented into 100-meter lengths and assigned unique ID numbers used to determine the location. Road segment conditions, lengths, and connectivity can be updated during REI field assessments.
Hydrologic Connectivity	Hydrologic connectivity is determined by a GIS proximity analysis.
Slope	Road slope is calculated by GIS and field verified during the REI.
Surface Type	Paved or unpaved
Road Types	Paved and unpaved roads with ditches, paved roads with curbs and catch basins, or Class 4 Roads
Road Condition	Compliance with MRGP standard pre-construction and post-construction: *Fully Meets*, *Partially Meets*, or *Does Not Meet*
Lifespan of Road Projects	Jurisdictional and sub-jurisdictional road projects are assumed to have an 8-year lifespan based on previous studies (Garton, 2015). Under the MRGP, jurisdictional road projects are assessed/renewed approximately every 5 years or MRGP permit cycle.

[5] For more information on REI data collection, please visit: https://vtanr.maps.arcgis.com/home/item.html?id=fe11c5ffd0d04eeca968115d84dacf90.

b. Data Management

All municipal road data (Table 1) are stored in the MRGP Implementation Table Portal.[6] The database contains geographic information about all road segments, slope, road type, location, and compliance condition. Once Regional Planning Commissions (RPCs), Natural Resource Conservation Districts (NRCDs), consultants and/or municipalities complete REIs and submit data to DEC, data are uploaded and publicly displayed on the MRGP Implementation Table Portal. Road erosion scoring can also be displayed spatially on the Natural Resources Atlas.[7]

c. Data QA/QC

Road segment data from REIs are imported to the MRGP Implementation Table Portal from Survey123 or spreadsheets. Both data paths require a minimum data standard be met before a road segment assessment can be submitted to the database. Data entries failing the minimum data requirements are scored as incomplete. When calculating phosphorus reductions, any segment with incomplete data will be superseded by the last score in the database or will be equivalent to *Does Not Meet* standards. Several database reports have also been developed to flag scoring outliers in order to inform DEC staff which municipalities should be prioritized for field reviews of segments assessments.

After towns successfully submit REI data to DEC, they must pay an administrative fee and sign an MRGP Amendment form to comply with the permit. DEC reviews these submittals for completeness, then posts an REI submittal report summary on public notice for 14 days.

d. Road Practice Verification

REIs will be conducted by municipalities, RPCs, or other entities approximately every five years or at least once in each MRGP permit cycle. Each municipality will annually report to DEC on progress bringing non-compliant roads up to MRGP standards during that year. As the MRGP relies mainly on self-reporting from municipalities, DEC staff will also audit road projects on a case by case basis. A regulatory verification protocol will be established after REIs have been completed and municipalities start implementation.

DEC has developed a BMP Verification method for clean water projects that helps provide accountability for state-funded projects over time. BMP Verification involves visual inspection of installed practices to ensure functionality over the expected lifespan of the project.

Road improvement projects completed under grant programs are required to assess and report on pre- and post-remediation road segment condition. These post-remediation assessments are essential for phosphorus accounting but do not ensure the project will be maintained over the

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[6] To access the MRGP Implementation Table Portal, please visit: https://anrweb.vt.gov/DEC/IWIS/MRGPReportViewer.aspx?ViewParms=True&Report=Portal.

[7] A map layer of "Road Erosion Scoring (MRGP)" can be displayed on the Natural Resource Atlas under the "Stormwater" layer or Municipal Roads Theme. If a road erosion inventory has been completed for a municipality, the road condition of each segment will be displayed on the map. The Atlas can be accessed at: http://anrmaps.vermont.gov/websites/anra5/.

long term. Under the Municipal Roads GIA Program, RPCs conduct pre-remediation and post-remediation assessments on each road segment brought into compliance with MRGP standards. Before towns can be reimbursed for the projects completed under the GIA Program, RPCs must verify that projects have been completed and segments have been brought up to standard. Similarly, projects funded through VTrans grant programs (Better Roads, Transportation Alternatives, etc.) must provide photos of completed projects before grants are administratively closed out.

IV. Phosphorus Loading Rates

Baseline paved and unpaved road phosphorus loading rates were derived from the 2001-2010 Lake Champlain TMDL Soil and Water Assessment Tool (SWAT) model (Tetra Tech, 2015). The SWAT model's paved road loading rates were derived from published literature values for the northeastern United States (Artuso et al., 1996; Budd and Meals 1994; Stone Environmental 2011). The TMDL SWAT model based unpaved loading rates on Wemple (2013), which measured sediment loading rates from unpaved roads in the Mad River watershed of Vermont. Sediment loading rates were converted to phosphorus loading rates, which produced an average estimated total phosphorus loading rate of 10 kg/km/yr. Using GIS estimates of hydrologic connectivity, Wemple (2013) estimated that only approximately 50% of the sediment and phosphorus eroded from roads is discharged directly to receiving waters. The TMDL SWAT model calibrated unpaved loading rates to the Wemple (2013) monitoring data and factored in the 50% hydrologic connectivity. The load averaged across connected and unconnected segments in the Lake Champlain basin was approximately 5 kg/km/yr, which factored about 10 kg/km/yr for connected segments, consistent with Wemple (2013).

a. Pre-MRGP Generalized Linear Phosphorus Loading Rates

In 2017, DEC discovered that that the TMDL SWAT model road areas greatly exceeded the road areas in the 2011 Lake Champlain Basin Impervious Surface GIS Layer.[8] As the 2011 impervious surface data layer is more detailed than the SWAT impervious surface layer, DEC adjusted road areas to match 2011 data layer. Impervious areas were divided based on road surface type and road class groupings. It was determined that the "Class 4 Impervious" grouping significantly undercounted road surface, so impervious area for these segments was estimated by buffering the road centerlines to 12 feet wide, as was consistent with previous observations and measurements made by DEC. These analyses resulted in new generalized phosphorus loading rates for paved and unpaved roads in the Lake Champlain and Lake Memphremagog basins.

[8] To access the 2011 Lake Champlain Impervious Surface GIS Layer, please visit: https://geodata.vermont.gov/datasets/738766d2549b49ab80c573408e300215_7.

Generalized linear phosphorus loading rates (kg/km/year) for the Lake Champlain basin were estimated using road phosphorus loads from the Lake Champlain TMDL SWAT model (Tetra Tech, 2015) and road length from VTrans centerline GIS data.[9]

$$Generalized\ P\ loading\ rate = \frac{total\ (paved\ or\ unpaved)\ road\ P\ load\ in\ drainage\ area\ (\frac{kg}{yr})}{length\ of\ (paved\ or\ unpaved)\ road\ in\ drainage\ area\ (km)}.$$

This analysis produced generalized phosphorus loading rates for paved and unpaved roads within each unique lake segment-drainage area combination (e.g., South Lake B-Mettawee River, Malletts Bay-Lamoille River; Appendix B, Table B-1).

Generalized linear phosphorus loading rates (kg/km/year) for the Lake Memphremagog basin were calculated using the total phosphorus loading rate per Lake Memphremagog TMDL drainage area divided by average road width of ten meters per road type (paved, unpaved) per TMDL drainage area. The loading rates are unchanged from the Lake Memphremagog TMDL model, but each drainage area is adjusted using a delivery factor.

The generalized phosphorus loading rates are used for road improvement projects implemented under the VTrans Better Roads Grants during SFY 2016-2019 because they did not collect REIs or pre-construction assessments to serve as the baseline for phosphorus accounting. Generalized phosphorus loading rates were also applied to Municipal Roads Grants-in-Aid projects during SFY 2017-2019 before MRGP-specific loading rates were developed (see Section B below).

b. MRGP Linear Phosphorus Loading Rates

The paved and unpaved road generalized loading rates did not establish different loading rates for the various road classifications associated with the 2018 MRGP (Table 2). To develop more specific loading rates for MRGP phosphorus accounting, DEC performed additional analyses to estimate baseline phosphorus loading rates for various road classifications in the Lake Champlain basin.

The goal of the new loading rate development was to set loading rates that reflect the relative phosphorus load from different combinations of loading factors (Table 2) without changing the total phosphorus load from municipal roads as estimated by the Lake Champlain SWAT model. Municipal roads were classified based on a combination of surface type, hydrologic connectivity, road class, slope class, and compliance score. All factors except compliance score were based on existing GIS layers. Available REI compliance score data were used to assign road lengths to each compliance class.

[9] To access the Vermont road centerline GIS dataset, please visit: https://geodata.vermont.gov/datasets/1dee5cb935894f9abe1b8e7ccec1253e_39.

DEC used the *Solver* add-in for Microsoft Excel to develop loading rates for each combination of loading factors (Table 2). *Solver* adjusted the generalized phosphorus loading rate (see Section IV.a) using a set of multipliers for hydrologic connectivity, road slope, and MRGP compliance status. The multiplier for hydrologic connectivity was set so that road length multiplied by the new loading rates matched the initial SWAT load. Multipliers for compliance score were based on the phosphorus accounting methodologies (see Section V). In the unpaved loading rate model, multipliers for slope were derived from Figure 8 of Wemple (2013), which illustrates that higher road slopes are associated with greater erosion. In the paved loading rate model, multipliers for slope were discounted from the unpaved model, as slope has less of an effect on paved phosphorus loading rates according to Figure 3.12 in Stone Environmental (2011). The unpaved loading rate models were also constrained using the 10 kg/km/yr average measured loading rate from Wemple (2013). Final MRGP linear loading rates are available in Appendix C.

Table 2. Loading factors used to estimate phosphorus loading rates.

Loading Factor	Variables
Road Type	Paved, Unpaved
Hydrologic Connectivity	Connected, Unconnected
Road Class	Class 1-3, Class 4 (unpaved only)
Road Slope	<5%, 5-10%, >10%
Compliance Status	*Does Not Meet, Partially Meets, Fully Meets*

V. Phosphorus Accounting Methodologies

In order to track and report progress towards achieving TMDL phosphorus reduction goals, DEC estimates phosphorus reductions associated with road improvement projects. Phosphorus accounting methodologies for road improvement projects can be divided into two time periods: pre-MRGP authorization and post-MRGP authorization.

a. Pre-MRGP Accounting Methodology

Road improvement projects constructed between 2010 and 2015 would not be able to receive credit toward the Lake Champlain TMDL unless all data required to calculate reductions (Table 1) were provided to DEC. It is not likely that any road projects implemented would have met MRGP standards prior to 2015, as the MRGP standards were not yet developed and no REIs had been conducted. DEC considers requests for phosphorus reduction credit of projects completed during this time on a case-by-case basis.

Generally, a pre- and post-construction assessment is required to receive credit for a road improvement project. Some road improvement projects that have been implemented without a pre-construction MRGP compliance assessment (i.e., non-Grants-in-Aid projects), however, may receive phosphorus loading reductions. For example, the VTrans Better Roads grant agreements may not require pre-and post-construction assessments to be completed. In the absence of these assessments, a 40% phosphorus reduction credit may be applied based on the assumption that the road project improved the compliance score but may not have fully brought the segment into compliance (see Section B below).

During 2016 and 2017, DEC had developed draft MRGP standards. Before the MRGP was formally authorized, some towns began conducting REIs with DEC approval. The draft MRGP standards were very similar to the final MRGP standards, so the Post-MRGP Accounting Methodology (below) was applied to those road improvement projects during this time.

b. Post-MRGP Accounting Methodology

Phosphorus accounting methodologies after MRGP authorization vary based on the type of road improvement project.

i. Accounting for Paved and Unpaved Roads with Ditches (excluding Class 4)

MRGP standards for paved and unpaved roads with ditches are based on the implementation of a suite of practices both on the road surface and within the ditch (Appendix A). Rather than accounting for nutrient load reductions at the individual road BMP-level, DEC accounts for road nutrient load reductions at the road segment-level based on compliance with MRGP standards.

REIs or pre-construction assessments determine if a road segment *Fully Meets*, *Partially Meets* or *Does Not Meet* MRGP standards, and this assessment serves as the baseline for phosphorus accounting. The baseline phosphorus loading rate is determined using the methods in Section IV. Road improvement projects implemented after an REI or a pre-construction assessment will be given credit towards phosphorus load reductions.

Phosphorus reduction efficiencies (Table 3) were developed based on the Wemple and Ross (2015) field study. Wemple and Ross (2015) measured sediment reductions associated with individual road BMPs rather than reductions resulting from a suite of practices based on MRGP compliance. To account for phosphorus reductions based on MRGP compliance, DEC and VTrans staff formed a workgroup to develop and adopt adjusted reduction efficiencies. For projects that result in the compliance status changing from *Does Not Meet* to *Fully Meets*, an 80% phosphorus load reduction is assigned. 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 assigned. These percent reductions are applied to the baseline linear loading rates in Appendix C.

Table 3. Total phosphorus load reduction efficiencies based on change in MRGP 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

ii. Accounting for Class 4 Roads

The MRGP standard for Class 4 roads requires the only the stabilization of gully erosion, rather than the suite of practices required on road Classes 1-3. Gully erosion is defined as erosion equal to or greater than 1 foot in depth. The following gully erosion accounting methodology will be used until more information is available for estimating erosion rates from paved and unpaved roads in Vermont.

Phosphorus crediting for Class 4 road remediation is based on the initial measured volume of erosion and road segment slope recorded in the REI. Sites with an erosion volume of three cubic yards or greater are considered "Very High Priority" for remediation. This volume was selected as the starting point for phosphorus load reduction efficiencies.

As Class 4 roads in Vermont are not designed for heavy travel, the MRGP standards for Class 4 roads are less onerous than standards for paved and unpaved roads with ditches. Bringing a "Very High Priority" Class 4 road segment into MRGP compliance (>10% road slope, ≥ 3 cubic yards erosion remediated) is assigned the equivalent phosphorus reduction efficiency as bringing a Class 1-3 segment from *Not Meeting* to *Partially Meeting,* or a 40% phosphorus load reduction (Table 3). Phosphorus reduction efficiencies for lower erosion volumes were then prorated due to lower quantities of erosion. These phosphorus reduction efficiencies are applied to the baseline post-MRGP linear loading rate in Appendix C.

Table 3. Phosphorus reduction credits for improvements on Class 4 roads resulting in full MRGP compliance.

Pre-construction Erosion Volume	Compliant Phosphorus Credit
< 3 cubic yards	20%
≥ 3 cubic yards	40%

iii. Accounting for Paved Roads with Catch Basin Outlets

MRGP standards for paved roads with catch basin outlets state that any gully or rill erosion associated with a catch basin outlet must be remediated. Gully erosion is severe erosion defined as equal or greater than 12” in depth, whereas rill erosion is moderate erosion defined as rivulets greater than 1” but less than 12” in depth. If erosion is equal to or greater than three cubic yards, projects are considered “Very High Priority” for remediation by Dec 31, 2025. For projects improving rill and gully erosion at catch basin outlets, the following accounting methodology will be used until more information is available for estimating erosion rates from paved and unpaved roads in Vermont.

A volumetric approach is used to estimate phosphorus reductions associated with improvements to catch basin outlet gully erosion improvements. First, the rate of erosion (Table 4, Equation 1) is calculated using volume measurements from the REI, standard sediment bulk density, and the estimated age of erosion (Table 4-Table 5). If the permittee measures more than one section of the rill or gully, the average length, width, and depth is used to calculate volume of erosion.

The age of erosion can be determined by one of two methods:

1. A normalized control of 30 years for the initial age of erosion can be adopted from the Maryland Department of Transportation (MDOT) Alternative Headwater Channel and Outfall Crediting Protocol method.[10] The literature suggests erosion occurs between 10 and 51 years, with potential stabilization occurring between 50 and 100 years (MDOT, 2018). This is the default method being used by DEC.
2. Alternatively, municipalities may use known dates or ages for the erosion or outlet structure. Supporting evidence must be attached to the permittees’ annual report and stormwater management plan (i.e. aerial imagery, past communication, time stamped photos, past finalized design plans that were constructed, known system implementation dates, known system repairs and erosion mitigation in the past 30 years). This evidence will be reviewed by the analyst when the proceeding annual report is submitted.

The rate of erosion is then multiplied by a sediment-to-phosphorus ratio to calculate the baseline phosphorus loading rate (Table 4; Equation 2), which is used to gage future erosion occurring at an outlet. The phosphorus reduction is based on the difference between the initial condition, measured before mitigation, and the repaired condition reported in annual reports (Table 4; Equation 3). Additional information and assumptions regarding the volumetric approach can be found in Appendix D.

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[10] Maryland Department of Transportation (MDOT) Alternative Headwater Channel and Outfall Crediting Protocol can be accessed at: https://www.roads.maryland.gov/OED/2018-02-26_Rev%202018-03-20%20Alternative%20Headwater%20Channel%20and%20Outfall%20Crediting%20Protocol.pdf.

Phosphorus reductions will be assigned to projects unless the condition of the outlet no longer *Fully Meets Standards* in subsequent REIs. If conditions at the site deteriorate, credit may decrease or be eliminated until repairs are performed.

Table 4. Equations used to calculate phosphorus load reductions associated with gully erosion improvements (USDA, 2002). More information provided in Appendix D.

	Formula
Equation 1: Rate of Erosion	$E = (VS) / T$
Equation 2: Phosphorus Loading Rate	$P_i = E (Sc)$
Equation 3: Phosphorus Reduction	$P_i - P_{ii} = P_f$

Table 5. Variables used in catch basin outlet phosphorus reduction calculations. Variables further explained in Appendix D.

Variable	Description	Directions	Units	Source
V	Total volume of erosion measured from outlet	Length x Avg. Width x Avg. Depth	ft^3	------
S	Sediment bulk density	43.38	kg / ft^3	Average moist bulk densities from USDA NRCS
T	Age of erosion observed	30 years or known age of erosion	Years	------
E	Sediment erosion rate	Calculate with Eq. 1	kg sediment (TSS) / year	------
Sc	Sediment to Phosphorous weight conversion	0.000396	kg (P)/ kg sediment (TSS)	Wemple (2013) Similar to MDOT (0.0005 kg P/ kg TSS)
P_i	Phosphorus loading rate, pre-mitigation	Calculate with Eq. 2	kg (P) / year	------
P_{ii}	Phosphorus loading rate, post-mitigation	------	kg (P) / year	------
P_f	Difference in phosphorus loading rate	Calculated only when the outlet has erosion post-mitigation	kg (P) / year	------

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Appendix A. MRGP Standards & Definitions

Table A-1. Road features, standards, and compliance scores under the MRGP. Compliance scores: Does Not Meet (DNM), Partially Meets (PM), or Fully Meets (FM). Gully erosion is severe erosion defined as equal or greater than 12" in depth, whereas rill erosion is moderate erosion defined as rivulets greater than 1" but less than 12" in depth.

Class 1-3 Paved and Unpaved Roads with Ditches		
Road Feature	**Standards Required**	**Compliance Scores**
Roadway Crown	Gravel roads shall be crowned, in-sloped or out-sloped, by a minimum of 2%.	DNM: 0-49% in place PM: 50-89% in place FM: ≥90% in place
Shoulder Berms	Shoulder berms shall be removed to allow precipitation to shed from the travel lane into the road drainage system.	DNM: 0-49% in place PM: 50-89% in place FM: ≥90% in place
Road Drainage	If distributed flow is possible, road shoulder shall be lower than the travel lane within the right-of-way. If distributed flow is not possible, ditches shall meet following standards according to road slope: • < 5%: grass-lined • ≥ 5-8%: stone-lined or grass-lined with check dams or two or more cross culverts or turn outs • ≥ 8%: stone-lined	DNM: 0-49% in place PM: 50-89% in place FM: ≥90% in place
Drainage Outlets and Turnouts	If distributed flow is possible, road drainage shall flow to a grass or forested filter area (road shoulder lower than travel lane). If distributed flow is not possible, turnouts shall meet the following standards according to embankment slopes: • < 5%: stabilize with grass • ≥ 5%: stabilize with stone	DNM: gully erosion FM: no erosion (or less than 1" in depth)
Drainage and Driveway Culverts	Rill or gully erosion must be stabilized by replacing or retrofitting culvert. Does not apply to perennial stream crossings.	DNM: gully erosion PM: rill erosion FM: no erosion (or less than 1" in depth)

Overall Segment Compliance Scoring	Compliance scoring for the entire segment is based upon the scoring of the above individual parameters.	DNM: ≥ 3 parameters Partially Meet, or ≥ 1 Does Not Meet PM: 1 or 2 Partially Meet, remaining Fully Meet FM: All parameters Fully Meet
Class 4 Roads		
Road Feature	Standards Required	Compliance Scores
Erosion	Any gully erosion that is one foot or deeper must be remediated.	DNM: gully erosion FM: rill/no erosion
Paved Roads with Curbs and Catch Basins		
Road Feature	Standards Required	Compliance Scores
Catch Basin Outlet Erosion	Stabilize rill and gully erosion.	DNM: gully erosion PM: rill erosion FM: no erosion (or less than 1” depth)

Appendix B. Generalized Phosphorus Loading Rates

Table B-1. Generalized road phosphorus loading rates for the Lake Champlain basin. Data modified from Tetra Tech (2015).

Lake Segment	Drainage Area	Loading Rate (kg/km/yr)	
		Paved Roads	Unpaved Roads
BURLINGTON BAY	Burlington Bay - CSO	2.296	0.000
BURLINGTON BAY	Burlington Bay - DD	1.872	5.744
ISLE LA MOTTE	Isle La Motte - DD	2.140	5.370
MALLETTS BAY	Lamoille River	2.679	6.784
SHELBURNE BAY	LaPlatte River	2.084	6.399
OTTER CREEK	Lewis Creek	3.248	6.264
OTTER CREEK	Little Otter Creek	2.996	6.512
MAIN LAKE	Main Lake - DD	2.705	6.909
MALLETTS BAY	Malletts Bay - DD	2.092	4.366
SOUTH LAKE B	Mettawee River	3.064	6.338
MISSISQUOI BAY	Missisquoi Bay - DD	4.077	1.504
MISSISQUOI BAY	Missisquoi River	3.280	6.175
NORTHEAST ARM	Northeast Arm - DD	2.522	5.589
OTTER CREEK	Otter Creek	2.483	6.839
OTTER CREEK	Otter Creek - DD	2.682	7.872
PORT HENRY	Port Henry - DD	2.623	6.606
SOUTH LAKE B	Poultney River	2.627	7.530
SOUTH LAKE A	South Lake A - DD	3.256	7.426
SOUTH LAKE B	South Lake B - DD	3.758	8.524
ST ALBANS BAY	St. Albans Bay - DD	2.396	4.706
MAIN LAKE	Winooski River	2.580	7.067
	Basin-Wide Average	2.655	6.679

Table B-2. Generalized road phosphorus loading rates for the Lake Memphremagog Basin.

Drainage Area	Loading Rate (kg/km/yr)	
	Paved Roads	Unpaved Roads
Headwaters Black River	1.253	5.141
Lamphean Brook-Black River	1.381	5.667
Lords Creek	1.350	5.537
Black River	1.369	5.618
Headwaters Barton River	1.051	4.312
Willoughby Brook-Barton River	0.810	3.321
Willoughby River	0.947	3.885
Barton River	1.190	4.884
Headwaters Clyde River	0.440	1.805
Seymour Lake-Clyde River	0.137	0.564
Clyde River	0.778	3.194
Lake Memphremagog	1.269	5.208
Basin-Wide Average	1.312	5.361

Appendix C. MRGP Linear Loading Rates

Table C-1. MRGP unpaved Class 1-3 phosphorus loading rates (kg/km/yr) for the Lake Champlain basin. Data modified from Tetra Tech (2015). CSO = combined sewer overflow. DD = direct drainage to lake segment. % = road slopes. Data may be updated following completion of all REIs.

Drainage Areas	Hydrologically Connected Segments									Un-connected Segments
	Fully Meets MRGP Standards			Partially Meets MRGP Standards			Does Not Meet MRGP Standards			
	<5%	5-10%	>10%	<5%	5-10%	>10%	<5%	5-10%	>10%	
Burlington Bay - CSO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Burlington Bay - DD	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Isle La Motte - DD	1.054	3.506	6.130	3.162	10.518	18.391	5.271	17.530	30.652	1.005
Lamoille River	0.937	3.118	5.452	2.812	9.354	16.355	4.687	15.589	27.259	0.894
LaPlatte River	0.998	3.318	5.802	2.993	9.954	17.406	4.988	16.590	29.009	0.951
Lewis Creek	0.900	2.995	5.237	2.701	8.984	15.710	4.502	14.974	26.183	0.858
Little Otter Creek	1.246	4.145	7.248	3.739	12.436	21.745	6.232	20.727	36.242	1.188
Main Lake - DD	0.956	3.180	5.560	2.868	9.539	16.680	4.780	15.898	27.799	0.911
Malletts Bay - DD	0.957	3.184	5.568	2.872	9.553	16.703	4.787	15.921	27.839	0.913
Mettawee River	0.986	3.280	5.734	2.958	9.839	17.203	4.930	16.398	28.672	0.940
Missisquoi Bay - DD	1.046	3.481	6.086	3.139	10.442	18.258	5.232	17.403	30.430	0.997
Missisquoi River	1.026	3.412	5.966	3.077	10.235	17.897	5.129	17.059	29.829	0.978
Northeast Arm - DD	1.213	4.035	7.056	3.640	12.105	21.167	6.066	20.175	35.278	1.156
Otter Creek	0.851	2.831	4.950	2.553	8.492	14.850	4.256	14.154	24.749	0.811
Otter Creek - DD	0.884	2.939	5.139	2.651	8.818	15.418	4.419	14.696	25.697	0.842
Port Henry - DD	1.355	4.507	7.881	4.065	13.521	23.642	6.775	22.535	39.404	1.292
Poultney River	0.968	3.221	5.632	2.905	9.662	16.895	4.842	16.104	28.158	0.923
South Lake A - DD	0.915	3.044	5.322	2.745	9.131	15.966	4.576	15.218	26.610	0.872
South Lake B - DD	0.875	2.911	5.090	2.626	8.733	15.270	4.376	14.555	25.450	0.834
St. Albans Bay - DD	1.002	3.333	5.828	3.006	9.999	17.484	5.011	16.665	29.140	0.955
Winooski River	0.989	3.289	5.751	2.967	9.867	17.253	4.944	16.445	28.755	0.943

Table C-2. MRGP unpaved Class 4 phosphorus loading rates (kg/km/yr) for the Lake Champlain basin. Data modified from Tetra Tech (2015). CSO = combined sewer overflow. DD = direct drainage to lake segment. % = road slopes. Data may be updated following completion of all REIs.

Drainage Areas	Hydrologically Connected Segments						Unconnected Segments
	Fully Meets MRGP Standards		< 3 cubic yards Erosion		> 3 cubic yards Erosion		
	<10%	>10%	< 10%	> 10%	<10%	>10%	
Burlington Bay - CSO	8.212	22.368	10.949	29.824	13.686	37.280	1.222
Burlington Bay - DD	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Isle La Motte - DD	3.566	9.713	4.754	12.950	5.943	16.188	0.531
Lamoille River	3.711	10.108	4.948	13.477	6.185	16.847	0.552
LaPlatte River	3.762	10.247	5.016	13.663	6.270	17.079	0.560
Lewis Creek	4.003	10.904	5.338	14.539	6.672	18.174	0.596
Little Otter Creek	4.304	11.723	5.738	15.631	7.173	19.539	0.640
Main Lake - DD	3.796	10.339	5.061	13.786	6.326	17.232	0.565
Malletts Bay - DD	3.672	10.001	4.896	13.335	6.119	16.669	0.546
Mettawee River	4.204	11.451	5.605	15.268	7.006	19.084	0.626
Missisquoi Bay - DD	3.625	9.875	4.834	13.167	6.042	16.458	0.539
Missisquoi River	3.748	10.208	4.997	13.611	6.246	17.014	0.558
Northeast Arm - DD	3.708	10.101	4.944	13.468	6.180	16.834	0.552
Otter Creek	3.856	10.505	5.142	14.007	6.427	17.508	0.574
Otter Creek - DD	4.246	11.567	5.662	15.423	7.077	19.279	0.632
Port Henry - DD	4.058	11.053	5.410	14.737	6.763	18.422	0.604
Poultney River	4.121	11.224	5.494	14.966	6.868	18.707	0.613
South Lake A - DD	4.188	11.408	5.584	15.211	6.980	19.013	0.623
South Lake B - DD	4.382	11.936	5.842	15.914	7.303	19.893	0.652
St. Albans Bay - DD	3.670	9.996	4.893	13.328	6.116	16.661	0.546
Winooski River	4.024	10.963	5.366	14.617	6.707	18.271	0.599

Table C-3. MRGP paved municipal road phosphorus loading rates (kg/km/yr) for the Lake Champlain basin. Data modified from Tetra Tech (2015). CSO = combined sewer overflow. DD = direct drainage to lake segment. % = road slopes. Data may be updated following completion of all REIs.

Drainage Areas	Hydrologically Connected Segments									Un-connected Segments
	Fully Meets MRGP Standards			Partially Meets MRGP Standards			Does Not Meet MRGP Standards			
	<5%	5-10%	>10%	<5%	5-10%	>10%	<5%	5-10%	>10%	
Burlington Bay - CSO	1.555	2.073	2.592	4.665	6.220	7.775	7.775	10.367	12.959	1.230
Burlington Bay - DD	1.122	1.496	1.870	3.365	4.487	5.609	5.609	7.478	9.348	0.887
Isle La Motte - DD	0.786	1.048	1.310	2.357	3.143	3.929	3.929	5.238	6.548	0.621
Lamoille River	0.963	1.284	1.605	2.888	3.851	4.814	4.814	6.418	8.023	0.761
LaPlatte River	1.037	1.382	1.728	3.110	4.146	5.183	5.183	6.911	8.638	0.820
Lewis Creek	0.923	1.231	1.539	2.770	3.693	4.616	4.616	6.155	7.694	0.730
Little Otter Creek	1.126	1.501	1.877	3.378	4.504	5.630	5.630	7.507	9.384	0.890
Main Lake - DD	1.000	1.333	1.667	3.000	4.000	5.000	5.000	6.667	8.333	0.791
Malletts Bay - DD	0.899	1.199	1.499	2.698	3.597	4.496	4.496	5.995	7.493	0.711
Mettawee River	0.949	1.266	1.582	2.848	3.797	4.746	4.746	6.328	7.910	0.751
Missisquoi Bay - DD	1.041	1.387	1.734	3.122	4.162	5.203	5.203	6.937	8.672	0.823
Missisquoi River	1.013	1.350	1.688	3.038	4.051	5.064	5.064	6.752	8.440	0.801
Northeast Arm - DD	0.954	1.272	1.590	2.862	3.815	4.769	4.769	6.359	7.949	0.754
Otter Creek	0.946	1.262	1.577	2.839	3.786	4.732	4.732	6.310	7.887	0.748
Otter Creek - DD	0.869	1.159	1.449	2.608	3.477	4.347	4.347	5.795	7.244	0.687
Port Henry - DD	1.022	1.362	1.703	3.065	4.087	5.108	5.108	6.811	8.514	0.808
Poultney River	1.053	1.404	1.754	3.158	4.211	5.263	5.263	7.018	8.772	0.832
South Lake A - DD	0.967	1.289	1.611	2.900	3.867	4.833	4.833	6.444	8.055	0.764
South Lake B - DD	1.306	1.742	2.177	3.919	5.225	6.532	6.532	8.709	10.886	1.033
St. Albans Bay	0.992	1.323	1.654	2.977	3.969	4.961	4.961	6.615	8.269	0.784
Winooski River	1.145	1.527	1.908	3.435	4.580	5.725	5.725	7.634	9.542	0.905

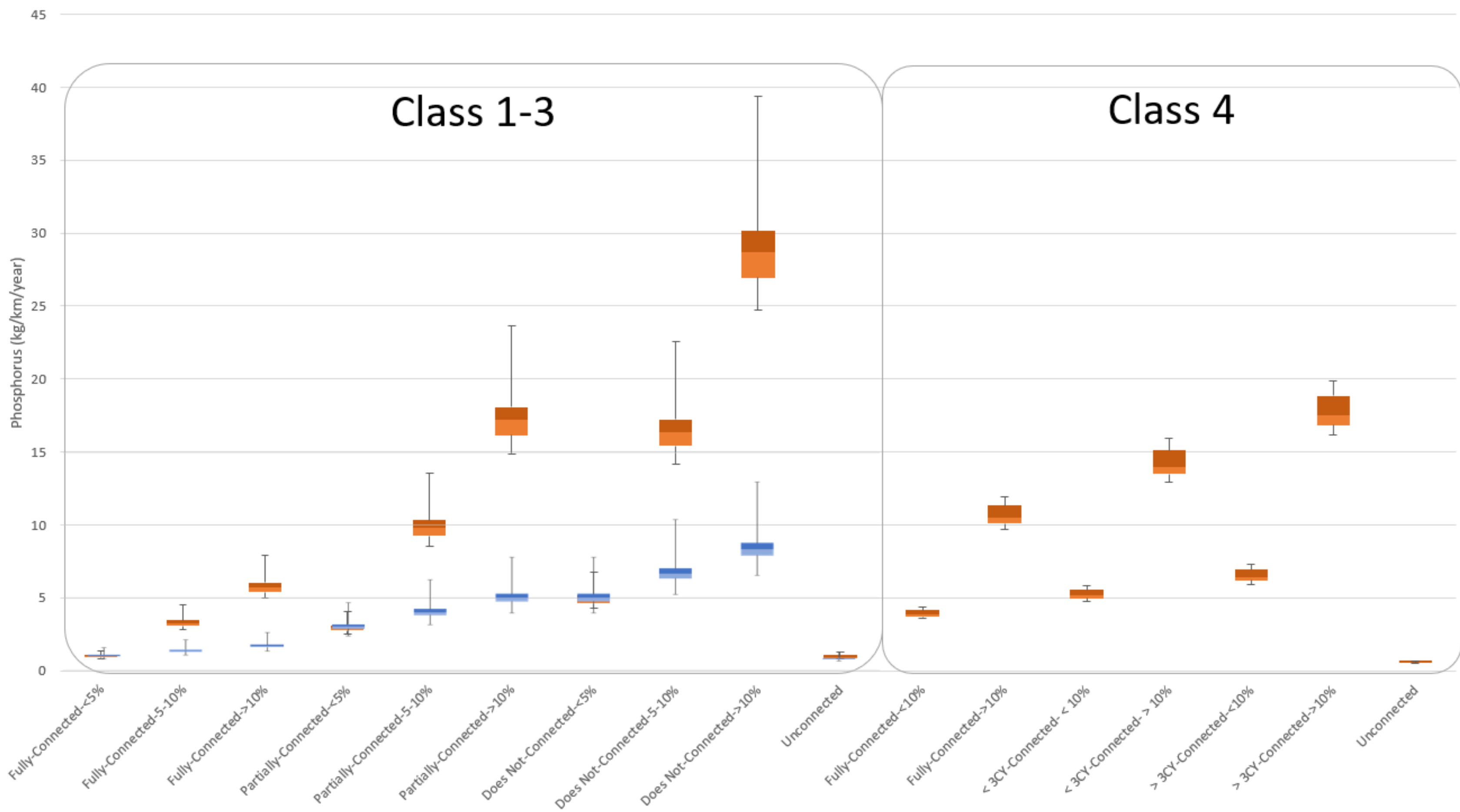

Figure C-1. Post-MRGP unpaved (orange) and paved (blue) loading rates for the Lake Champlain watershed. Data may be updated following completion of all REIs. X-axis labels represent different combinations of road segment classifications under the MRGP. For example, "Fully-Connected-<5%" represents road segments that Fully Meet standards, are hydrologically connected, and are sloped less than 5%.

Appendix D. Assumptions in Catch Basin Outlet Accounting

Additional assumptions, uncertainty, and ideas for future improvements

a) The current method does not account for upslope flow or erosion contributing to the erosion from catch basin outlets.

b) Remediating one outlet likely remediates erosion for multiple road segments, not just one. The current method only accounts for erosion at the end of the pipe and does not account for how many road segments are improved by the mitigation for one outlet.

c) The current method does not account for if the practice or road was installed correctly. There is not estimate % reduction for human error which may increase the amount of phosphorus discharging from road erosion.

d) It is assumed 100% of the erosion has the potential to flow to the nearest receiving body of water that directly impacts the Lake Champlain Basin.

e) The current method does not take into consideration loads that may result from sediments being transported by traffic or wind that may runoff from a paved road during rainfall or snowmelt events.

f) The current method applies the same phosphorus to TSS ratio from Wemple (2013) for unpaved road field assessments to paved roads with catch basins. Literature is sparse when it comes to identifying phosphorus erosion rates for paved roads.

g) For paved roads with catch basins, the volume observed/calculated is assumed to be soil and does not account for the sediment or phosphorus regularly discharging from a paved road. The percentage of road material contributed to the current condition is unknown.

h) The regular cleaning or maintenance of catch basins is not accounted for in the current method.