Standard Operating Procedures for Tracking & Accounting of Stormwater Permit Programs: Operational and Municipal Separate Storm Sewer (MS4) Permits

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Summary of Stormwater 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
Infiltration trench	Provides storage of runoff using the void spaces within the soil, sand, gravel mixture within the trench for infiltration into the surrounding soils.	Latitude, longitude Developed impervious acres treated Developed pervious acres treated Storage volume Infiltration rate	Average 90% (depends on storage volume and infiltration rate)	USEPA (2010)
Subsurface Infiltration	Provides storage of runoff using the combination of storage structures and void spaces within the washed stone within the system for infiltration into the surrounding soils.	Latitude, longitude Developed impervious acres treated Developed pervious acres treated Storage volume Infiltration rate	Average 90% (depends on storage volume and infiltration rate)	USEPA (2010)
Surface Infiltration	Provides storage of runoff through surface ponding (e.g., basin or swale) for subsequent infiltration into the underlying soils.	Latitude, longitude Developed impervious acres treated Developed pervious acres treated Storage volume Infiltration rate	Average 93% (depends on storage volume and infiltration rate)	USEPA (2010)
Rain Garden, Bioretention (no underdrains)	Provides storage of runoff through surface ponding and possibly void spaces within the soil, sand, washed stone mixture that is used to filter runoff prior to infiltration into underlying soils.	Latitude, longitude Developed impervious acres treated Developed pervious acres treated Storage volume Infiltration rate	Average 93% (depends on storage volume and infiltration rate)	USEPA (2010)
Rain Garden, Bioretention (with underdrain)	Provides storage of runoff by filtering through an engineered soil media. The storage capacity includes void spaces in the filter media and temporary ponding at the surface. After runoff passes through the filter media it discharges through an under-drainpipe.	Latitude, longitude Developed impervious acres treated Developed pervious acres treated Storage volume	Average 47% (depends on storage volume)	USEPA (2010)

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
Gravel Wetland	Provides surface storage of runoff in a wetland cell that is routed to an underlying saturated gravel internal storage reservoir (ISR). Outflow is controlled by an orifice that has its invert elevation equal to the top of the ISR layer and provides retention of at least 24 hours.	Latitude, longitude Developed impervious acres treated Developed pervious acres treated Storage volume	Average 61% (depends on storage volume)	USEPA (2010)
Porous Pavement (with infiltration)	Provides filtering of runoff through a filter course and temporary storage of runoff within the void spaces of a subsurface gravel reservoir prior to infiltration into subsoils.	Latitude, longitude Developed impervious acres treated Developed pervious acres treated Storage volume Infiltration rate	Average 90% (depends on storage volume and infiltration rate)	USEPA (2010)
Porous Pavement (with impermeable underlining or underdrain)	Provides filtering of runoff through a filter course and temporary storage of runoff within the void spaces prior to discharge by way of an underdrain.	Latitude, longitude Developed impervious acres treated Developed pervious acres treated Filter course depth	Average 70% (depends on storage volume and filter course depth)	USEPA (2010)
Sand Filter (with underdrain)	Provides filtering of runoff through a sand filter course and temporary storage of runoff through surface ponding and within void spaces of the sand and washed stone layers prior to discharge by way of an underdrain.	Latitude, longitude Developed impervious acres treated Developed pervious acres treated Storage volume	Average 47% (depends on storage volume)	USEPA (2010)
Wet Pond	Provides treatment of runoff by routing through permanent pool.	Latitude, longitude Developed impervious acres treated Developed pervious acres treated Storage volume	Average 53% (depends on storage volume)	USEPA (2010)
Extended Dry Detention Basin	Provides temporary detention storage for the design storage volume to drain in 24 hours through multiple outlet controls.	Latitude, longitude Developed impervious acres treated Developed pervious acres treated Storage volume	Average 12% (depends on storage volume)	USEPA (2010)
Grass Conveyance Swale	Conveys runoff through an open channel vegetated with grass. Primary removal mechanism is infiltration.	Latitude, longitude Developed impervious acres treated Developed pervious acres treated Storage volume	Average 19% (depends on storage volume)	USEPA (2010)

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
Mechanical Broom Sweeper	A vehicle with a rotating broom the brushes street sediment and debris into a hopper.	Drainage Area Developed impervious acres treated Developed pervious acres treated Sweeping Frequency	1-5% (depending on frequency)	Massachusetts MS4 General Permit (2016)
Vacuum-assisted Sweeper	A vehicle with a vacuum for removing street sediment and debris.	Drainage Area Developed impervious acres treated Developed pervious acres treated Sweeping Frequency	2-8% (depending on frequency)	Massachusetts MS4 General Permit (2016)
High Efficiency Regenerative Air Vacuum Sweeper	A vehicle that uses a blast of air to dislodge with a vacuum for removing street sediment and debris from the road surface, which is then vacuumed into a hopper.	Drainage Area Developed impervious acres treated Developed pervious acres treated Sweeping Frequency	2-10% (depending on frequency)	Massachusetts MS4 General Permit (2016)
Enhanced leaf collection on Streets with ≥ 17% Tree Cover	Use of any sweeper technology on streets with ≥ 17% tree cover at least four times in the fall to remove the majority of leaf fall.	Drainage Area Developed impervious acres treated Developed pervious acres treated Sweeping Frequency	17%	Wisconsin DEP (2017)
Catch Basin Cleaning	Removal of sediment and debris from catch basins.	Drainage Area Developed impervious acres treated Developed pervious acres treated	2%	Wisconsin DEP (2017)

I. Introduction

This document outlines the methods used by the Vermont Department of Environmental Conservation (DEC) to track and account for phosphorus reductions from regulatory stormwater practices implemented under the Operational Stormwater Permit and the Municipal Separate Storm Sewer System (MS4) permit. The primary focus is on tracking and accounting of stormwater practices described in the 2017 Vermont Stormwater Management Manual. This document also describes the methods of accounting for non-structural stormwater practices, such as street sweeping, catch basin cleaning, and leaf litter pick up, used by entities subject to the MS4 permit. Although the main focus of this document is regulatory stormwater practices, the tracking and accounting methods for non-regulatory structural and non-structural stormwater projects funded through state funding programs are also outlined below. Tracking and accounting methods for practices required by the Municipal Roads General Permit are described in the separate *Tracking & Accounting of Municipal Roads Practices SOP*.

Phosphorus reduction targets are key priorities in monitoring progress towards achieving the Lake Champlain and Lake Memphremagog Phosphorus Total Maximum Daily Load (TMDL). The Clean Water Service Delivery Act (Act 76 of 2019) requires addressing gaps in tracking and accounting and publishing methods to estimate phosphorus reductions for clean water projects implemented in these basins by November 2021. This document contains tracking and accounting methods for the majority of stormwater practices resulting in nutrient reductions, but there are some practices that are not described below (e.g., hydrodynamic separators). This SOP will be updated as new tracking and accounting methods are developed, and all methods are subject to change.

II. General Accounting Methodologies for Stormwater Treatment Practices

DEC has based stormwater treatment practice (STP) accounting methodologies on the Lake Champlain BMP Accounting and Tracking Tool (LC BATT) developed by US EPA, which is spreadsheet-based tool for the tracking and accounting of nutrient load reductions from non-point sources in the Lake Champlain basin.

Generally, estimated phosphorus reductions from structural STPs are calculated as the product the site area, baseline phosphorus loading rate of the area, and the phosphorus reduction efficiency (Figure 1).

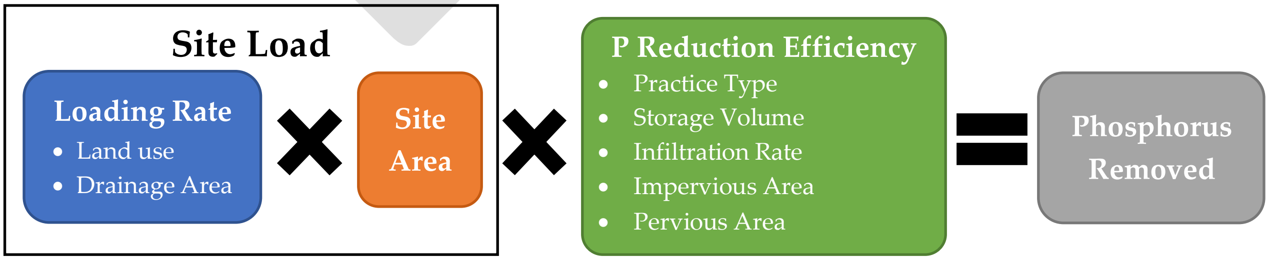

Figure 1. General accounting methodology used for structural STPs.

a. Baseline Phosphorus Loading Rates

Area-weighted baseline phosphorus loading rates for developed land uses in the Lake Champlain basin (Appendix A) were derived from the 2001-2010 TMDL Soil Water Assessment Tool (SWAT) model (Tetra Tech, 2015a). The SWAT model developed loading rates based on not only land use, but also different rates depending on the slope and hydrologic soil group of each land use. Area-weighted loading rates (kilograms per acre per year) were calculated by dividing the total phosphorus load for each land use type 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. To calculate a specific site's load, the acreage of each land use draining to a practice is multiplied by the appropriate loading rate, as shown in .

For DEC's accounting methodology, some loading rates were aggregated from those originally used in the SWAT model. Since many practices drain a combination of paved roads and non-road impervious land uses, a loading rate designated "Developed Impervious" was created as an area-weighted average of the paved roads and non-road impervious land uses. For projects where hydrologic soil group (HSG) is not available, a weighted average loading rate was calculated for "Developed Pervious." Loading rates were also averaged across slopes, as this data is not typically collected.

It should be highlighted that the TMDL baseline phosphorus loading rates were the result of watershed modeling results rather than direct loading measurements at study sites, so the model's generalized assumptions may not be applicable to all localized areas.

b. Structural STP Phosphorus Reduction Efficiencies

i. Structural Reduction Efficiency Calculations

Phosphorus reduction efficiencies of structural STPs (Appendix B) were determined using best management practice (BMP) performance curves developed by EPA (US EPA 2010). BMP performance curves are used to estimate cumulative phosphorus reduction efficiencies according to the size (i.e. storage volume) of the practice.

The storage volume is the amount of water that an STP can hold. For phosphorus accounting calculations, the storage volume used is the volume of water an STP can hold during storms up to the 1-year return storm, as calculated by the storage volume equations outlined in Appendix C. Some practices are designed to provide attenuation and safe passage of larger storms, such as the 10- or 100-year return storm; however, this additional volume typically does not remain in the STP long enough to receive significant treatment and should not be included in phosphorus accounting calculations.

To use BMP performance curves, the storage volume must be expressed in inches of runoff from impervious surfaces that the STP can treat. The runoff depth is calculated using the storage volume of the practice and the acreage of impervious and pervious areas draining to that practice.

Runoff depth is calculated as follows, as modified from LC BATT:

Impervious	$R_I = P$
Pervious HSG A	$R_A = 0.0413 \times P^2 - 0.0118 \times P$
Pervious HSG B	$R_B = 0.0652 \times P^2 - 0.0231 \times P$
Pervious HSG C	$R_C = 0.2 \times P^2 - 0.0597 \times P$
Pervious HSG D	$R_D = 0.2746 \times P^2 + 0.0057 \times P$

Where:
P = Precipitation (inches)
R_I = Runoff from impervious areas (inches)
R_A = Runoff from pervious areas with hydrologic soil group A (inches)
R_B = Runoff from pervious areas with hydrologic soil group B (inches)
R_C = Runoff from pervious areas with hydrologic soil group C (inches)
R_D = Runoff from pervious areas with hydrologic soil group D (inches)

The storage volume is calculated as the sum of the runoff depth for each land use type, multiplied by the area of each land type draining to the practice.

$$V = (A_I \times R_I + A_A \times R_A + A_B \times R_B + A_C \times R_C + A_D \times R_D) \times 43560/12$$

Where:
V = Storage volume of the treatment practice (feet^3)
A_I = Impervious surface (acres)
A_A = Pervious area over hydrologic soil group A (acres)
A_B = Pervious area over hydrologic soil group B (acres)
A_C = Pervious area over hydrologic soil group C (acres)
A_D = Pervious area over hydrologic soil group D (acres)

The equations above can then be substituted into the storage volume equation:

$$\begin{aligned} V = {} & A_I \times R_I + A_A \times (0.0413 \times R_I^2 - 0.0118 \times R_I) + A_B \times (0.0652 \times R_I^2 - 0.0231 \times R_I) \\ & + A_C \times (0.2 \times R_I^2 - 0.0597 \times R_I) + A_D \times (0.2746 \times R_I^2 + 0.0057 \times R_I) \times 3630 \end{aligned}$$

Both DEC's tracking and accounting database, the Watershed Projects Database (WPD), and the online STP Calculator tool solve for R_I using an iterative approach. R_I can also be solved by rearranging and solving by the quadratic equation. The following solution is used to calculate storage depth in a spreadsheet:

$$\begin{aligned} R_I = -(3630 \times A_I - 42.834 \times A_A - 83.853 \times A_B - 216.711 \times A_C + 42.834 \times A_D) \\ - \Big(\big((3630 \times A_I - 42.834 \times A_A - 83.853 \times A_B - 216.711 \times A_C + 42.834 \times A_D)\big)^2 \\ + 4 \times (149.919 \times A_A + 236.676 \times A_B + 726 \times A_C + 996.798 \times A_D) \times V\Big)^{1/2} \\ /\big(2 \times (149.919 \times A_A + 236.676 \times A_B + 726 \times A_C + 996.798 \times A_D)\big) \end{aligned}$$

ii. Generalized Phosphorus Reduction Efficiencies

In some instances, not enough practice sizing data is available to calculate phosphorus reductions for structural STPs. As a result, DEC developed generalized phosphorus reductions (Appendix D) based on typical practice sizes designed to meet the water quality standard per the Vermont Stormwater Management Manual.

c. Non-Structural STP Phosphorus Reduction Efficiencies

Phosphorus credits can also be awarded for non-structural STPs, including street sweeping, catch basin cleaning and leaf litter pick-up, although current tracking is limited. Phosphorus reduction efficiencies (Table 1) are applied to the developed lands treated within the right-of-way (roadway plus municipal easement). Phosphorus credits from monthly and weekly practices are assumed to be performed year-round. If sweeping is only performed during part of the year, the credit is prorated based on the percent of the year during which sweeping occurs.

Phosphorus credits are only given for an increase in street sweeping during or after the TMDL modeling period. Full credit is awarded for practices that started after the TMDL modeling period (2000-2010). For practices commenced or increased prior to 2010, credit is reduced by 10% for each year prior to 2010.

Efforts are currently underway to better understand the benefits of non-structural STPs in Vermont. Several municipalities in Chittenden, Franklin, Rutland, and Washington Counties are currently involved in a study with the U.S. Geological Survey (USGS) to determine the nutrient content of street and municipal solids in Vermont and estimate Vermont-specific leaf management credits. These new data, combined with existing information on current street practices, will provide a basis for the development of new phosphorus crediting incentive programs in Vermont. As a result, Table 1 is subject to change.

Table 1. Estimated phosphorus reduction efficiencies from Appendix F of the Massachusetts MS4 General Permit (2016) and Wisconsin Department of Environmental Protection (2017).

Sweeper Technology	Frequency	Phosphorus Reduction Efficiency
Mechanical Broom	2/year (spring and fall)	1%
Mechanical Broom	Monthly	3%
Mechanical Broom	Weekly	5%
Vacuum Assisted	2/year (spring and fall)	2%
Vacuum Assisted	Monthly	4%
Vacuum Assisted	Weekly	8%
High Efficiency Regenerative Air-Vacuum	2/year (spring and fall)	2%
High Efficiency Regenerative Air-Vacuum	Monthly	8%

Sweeper Technology	Frequency	Phosphorus Reduction Efficiency
High Efficiency Regenerative Air-Vacuum	Weekly	10%
Any technology on streets with ≥17% tree cover	4X in the fall	17%

A two percent (2%) credit can be applied to the road load if catch basins have material removed annually.

III. Operational Permit Tracking Methodologies

a. Permit Details

General Permit 3-9050[1] will cover all operational stormwater permitting in Vermont. Projects subject to stormwater discharge permitting must meet the treatment standards within the Vermont Stormwater Management Manual (VSMM). DEC regulates three types of impervious surfaces under the operational permitting program:

1. New impervious surface of one or more acres, or expansions resulting in an acre or more of impervious surface.
2. Re-developed impervious surface of an acre or more.
3. Existing impervious surface designated as requiring treatment in order to meet water quality goals, such as the requirement to regulate impervious surfaces of three acres or more that are not permitted under the 2002 or the 2017 VSMM.

b. Tracking Methodologies

Impervious and pervious surface area draining to a practice and practice type are obtained from permit application data and stored in the Stormwater Management Database. Certain data required for phosphorus accounting have not always been tracked in DEC's Stormwater Management Database. For example,

1. Rather than tracking the drainage area of each practice, the database has historically tracked drainage area by discharge point, which may contain multiple treatment practices.
2. Rather than tracking the storage volume of each practice, the database has historically tracked the treatment standards achieved for the drainage area.

DEC's Stormwater Program is working on modifications to the Stormwater Management Database to better capture information for individual practices, including storage volume of each practice. This will allow for the tracking of data needed to calculate phosphorus reductions and the automation of calculations within the database, where possible.

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[1] As of 5/20/2020, General Permit 3-9050 has not yet been finalized but will be issued sometime in 2020.

c. Accounting Methodologies

i. General Considerations

A land use change resulting in the creation of new impervious surfaces often results in an increase in phosphorus loading. Treating runoff from these impervious surfaces with STPs, however, can reduce or eliminate an increase in phosphorus loading. The net change in phosphorus loading is calculated as:

$$\begin{aligned}\Delta\, P\ Load\ from\ New\ Development &\\ &= (Post\ Development\ Load - Pre\ Development\ Load)\\ &- (Post\ Development\ Load\ \times \%\ Reduction\ from\ STP)\end{aligned}$$

Treatment of re-developed and existing impervious surfaces does not result in a change in land use, so treatment results in a net reduction in phosphorus, calculated as:

$$\begin{aligned}\Delta\, P\ Load\ from\ Redevelopment\ or\ Existing &\\ &= -(Post\ Development\ Load\ \times \%\ Reduction\ from\ Treatment\ Practice)\end{aligned}$$

If a project upgrades a previously built practice, then the resulting load reduction is the difference between the upgraded practice's load reduction and the original load reduction.

ii. Phosphorus Reduction Efficiencies

Phosphorus reduction efficiencies related to operational permit tracking have varied over time as data availability and tracking capabilities have increased.

In the Vermont Clean Water Initiative 2018 Investment Report & 2019 Performance Report[2], the following assumptions were made when accounting for phosphorus reductions from operational stormwater permits:

1. As STP storage volumes were not readily available for all practices, generalized phosphorus reductions (Appendix D) were estimated based on the typical treatment depth of each practice type required to meet the water quality standard. Practices designed to meet the water quality standard of the 2002 VSMM were sized to treat 0.9" of precipitation and those designed to meet the 2017 VSMM standard were sized to treat 1.0" of precipitation.
2. Permit applications received by DEC on or before 6/30/2017 were issued under the 2002 VSMM, whereas applications received on or after 7/1/2017 had to comply with the standards in the 2017 VSMM. Phosphorus reductions from the 2002 or 2017 VSMM sizing requirements were assigned based on the application received date.
3. If the area draining to one discharge point contained more than one practice, the total drainage area and phosphorus load were divided equally amongst the practices.
4. Redevelopment received 20% of the generalized reduction under the 2002 VSMM and 50% of the generalized reduction under the 2017 VSMM. This is because the 2002 VSMM and the 2017 VSMM manuals specify that for redeveloped area 20% or 50%, respectively of the water quality volume must be treated.

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[2] Clean Water Initiative Program Annual Reports: https://dec.vermont.gov/water-investment/cwi/reports

5. Where the most recently issued permit superseded a previous permit, the net change in phosphorus load was calculated by subtracting the previous phosphorus load from that of the most recent permit.

d. Operation & Maintenance Requirements

Structural STPs authorized under an operational permit have operation and maintenance (O&M) requirements. O&M reports are submitted and processed in ANR Online[3] and tracked by DEC in the Stormwater Management Database. The following O&M reports are submitted to DEC:

1. Designer Initial Statement of Compliance (DISOC) report tracks when a permitted stormwater system has been constructed and certifies its compliance.
2. Designer Restatement of Compliance (DROC) report tracks the status of compliance for the permitted stormwater system and indicates the designer's responsibilities under the permit.
3. Annual inspection reports track project completeness and include a maintenance inspection checklist that includes good housekeeping practice specifics (i.e. mowing, sediment removal from catch basins, and erosion prevention).

Stormwater technical staff also conduct field site inspections for issued permits to confirm compliance. Any non-compliance reported, via O&M reports, site inspection or complaint, allow the program to work with permittees to bring their authorization back into compliance. Non-compliance resolutions may be (1) accomplished voluntarily by the permittee, or (2) result in a notice of alleged violation (NOAV) or other form of enforcement action depending on the severity of the documented non-compliance. All non-compliance actions are tracked in the DEC's Stormwater Management Database and DEC's enforcement database.

IV. MS4 Permit Tracking Methodologies

a. Permit Details

The 2018 Municipal Separate Storm Sewer System General Permit (MS4) requires MS4 municipalities to develop and implement Phosphorus Control Plans (PCPs) to address the Lake Champlain TMDL's developed lands waste load allocation. In addition, MS4 municipalities are required to develop and submit Flow Restoration Plans (FRP) if they contain stormwater impaired watersheds within their boundaries. Progress implementing FRPs is reported annually. PCPs must be submitted to the State by April 1, 2021; thereafter, PCP progress will be reported annually.

Stormwater treatment systems installed under the FRPs are intended to meet flow reduction targets, but many will also result in phosphorus reductions. Therefore, DEC will track and account for practices resulting from FRPs and PCPs. Practices constructed in 2002 or later are credited towards the PCP targets, which is earlier than the end of the TMDL modeling period (2010), but this was done to be consistent with the FRP crediting period.

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[3] ANR Online is an electronic form submittal portal available here: https://anronline.vermont.gov/

b. Tracking Methodologies

Prior to 2018, MS4s were not required to report on the details of stormwater practices installed outside of state funding programs. MS4 projects that received state funding, however, were captured in the WPD (See Non-regulatory Tracking Methodologies below).

Structural and non-structural STPs constructed after 2018, however, will be tracked within the MS4 Annual Report. The Annual Report will include an Excel spreadsheet (BMP Tracking Table) to track projects implemented by a municipality for FRPs and PCPs. The table will include all the information needed to calculate phosphorus reductions and also track construction, inspections, and maintenance of these practices.

c. Operation & Maintenance Requirements

MS4 permittees will report on the operation & maintenance of practices in operation during the previous calendar year in a report due April 1st each year. The report will include:

1. Extent of street sweeping and catch basin cleaning
2. Maintenance of structural treatment practices
3. Statement that structural practices built in the previous year were built in compliance with the approved plan.

Stormwater staff will review O&M changes each year and determine if practices are being maintained properly. All practices must be maintained in good condition to continue phosphorus crediting.

Stormwater staff will conduct desk audits of MS4 programs annually and may conduct field site inspections, as needed. Because the MS4 permit is under federal NPDES authority, the EPA can also choose to inspect or audit an MS4 program permitted by the State. Non-compliance documented will be handled similarly to operational permitting non-compliance.

d. Incorporation of Operational Permits into MS4

Some operational permits may be incorporated into MS4 authorizations under the control of the municipality. Phosphorus load reductions will be awarded for expired or issued operational permits being incorporated into MS4 authorizations if the impervious existed prior to 2002 and the treatment improved after 2002. Once controlled by the MS4, the site must be operated and maintained in compliance with the operational permit issued most recently for the impervious surface. Practice-specific O&M will be reported to the program through the MS4 Annual Report. The operational permit history within the database will be used by stormwater staff to review phosphorus loading changes reported in the BMP Tracking Table.

V. Non-regulatory Tracking Methodologies

DEC also funds and tracks numerous non-regulatory stormwater projects through state funding programs. Non-regulatory stormwater projects include grant or loan funded projects that implement structural STPs, such as infiltration basins or gravel wetlands, or the purchase of equipment to assist with non-structural STPs, such as vactor (vacuum) trucks or high efficiency street sweepers.

Grant recipients are required to submit a final report to DEC containing project performance measures and STP data needed to calculate phosphorus reductions. Non-regulatory stormwater projects are tracked in the WPD managed by the DEC’s Clean Water Initiative Program (CWIP). WPD tracks all the information necessary to calculate phosphorus reductions from various practice types, as described in Section II.

Grantees implementing non-regulatory stormwater projects are required to sign an Operation and Maintenance (O&M) Plan and Agreement. The purpose of the O&M Plan and Agreement is to outline maintenance items that need to be addressed throughout the life of the BMP and identify the responsible party. O&M Plans help ensure that the projects funded by DEC continue to have water quality benefits throughout their lifespan.

DEC has also developed a BMP Verification program to verify that funded BMPs continue to function properly after they have been constructed. Using a mobile application called Survey 123, DEC staff conduct field visits to note the functionality of existing structural STPs and where maintenance might be needed. DEC staff then follow-up with the responsible party from the O&M Plan and Agreement regarding the findings of the site visit.

VI. Data QA/QC & Verification

Regulatory and non-regulatory STP data from WPD and the Stormwater Management Database are ultimately housed in the Clean Water Reporting Framework (CWRF). DEC ensures minimum data standards (i.e., location, basin, town, phosphorus loads) for all stormwater projects are met before uploading data to CWRF. CWIP and the Stormwater Program also compare the Stormwater Management Database with WPD to remove duplicate practices before importing data into CWRF. Stormwater permit data outcomes and estimated phosphorus reductions are reported on annually in the Clean Water Initiative Performance Report.

VII. References

Tetra Tech, Inc. 2015. SWAT Model Calibration Report. Prepared for U.S. Environmental Protection Agency, Region I, by Tetra Tech, Inc., Fairfax, VA. November.

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US EPA. 2010. Stormwater Best Management Practices (BMP) Performance Analysis. U.S. Environmental Protection Agency, Region I, Boston, MA. March.

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VT DEC. 2017. Modeling documentation for the Lake Memphremagog TMDL.

Wisconsin Department of Environmental Conservation. 2017. Interim Municipal Phosphorus Reduction Credit for Leaf Management Programs. Madison, Wisconsin.

Appendix A. **Baseline Phosphorus Loading Rates for Developed Lands**

Table A-1. Lake Champlain basin phosphorus loading rates for developed lands (kg/acre/year). Data from Tetra Tech (2015).

Lake Segment	Drainage Area	Unpaved Roads	Paved Roads	Non-Road Impervious	Developed Impervious	Developed Pervious					Forest
						HSG A	HSG B	HSG C	HSG D	Weighted Average	
South Lake B	Mettawee River	2.299	0.823	1.197	1.040	0.062	0.273	0.420	0.787	0.289	0.259
South Lake B	Poultney River	2.259	0.839	1.169	1.012	0.142	0.137	0.164	0.643	0.289	0.261
South Lake B	South Lake B DD	2.381	1.097	1.464	1.298	0.036*	0.238*	0.947	0.412*	0.947	0.131
South Lake A	South Lake A DD	2.321	0.927	1.309	1.127	0.036*	0.238*	0.250	0.374	0.373	0.132
Port Henry	Port Henry DD	2.224	0.894	1.241	1.081	0.001	0.556	0.288*	0.506	0.503	0.073
Otter Creek	Lewis Creek	2.208	0.854	0.989	0.928	0.010	0.342	0.283	0.332	0.290	0.071
Otter Creek	Little Otter Creek	2.360	0.957	1.233	1.097	0.024	n/a	0.144	0.400	0.366	0.037
Otter Creek	Otter Creek	2.115	0.818	1.150	0.998	0.100	0.276	0.271	0.398	0.292	0.248
Otter Creek	Otter Creek DD	2.272	0.881	1.095	1.005	0.036*	0.238*	0.273	0.351	0.348	0.399
Main Lake	Main Lake DD	2.081	0.877	0.933	0.914	0.001	0.043	0.288*	0.301	0.095	0.268
Main Lake	Winooski River	2.207	0.802	1.117	0.980	0.020	0.254	0.284	0.467	0.231	0.181
Shelburne Bay	Laplatte River	2.075	0.735	0.952	0.878	0.010	0.059	0.123	0.243	0.172	0.061
Burlington Bay	Burlington Bay - CSO	n/a	0.921	1.651	1.449	0.015	0.158	0.288*	0.354	0.082	0.096
Burlington Bay	Burlington Bay DD	1.939	0.750	1.369	1.215	0.001	0.058	0.288*	0.340	0.064	0.170
Malletts Bay	Lamoille River	2.034	0.810	1.138	0.986	0.037	0.213	0.438	0.547	0.228	0.069
Malletts Bay	Malletts Bay DD	2.010	0.677	0.825	0.758	0.011	0.099	0.288*	0.392	0.012	0.028
Northeast Arm	Northeast Arm DD	2.067	0.819	1.144	1.002	0.036*	0.238*	0.104	0.298	0.298	0.342
St. Albans Bay	St. Albans Bay DD	1.992	0.791	1.240	1.059	0.036*	0.049	0.194	0.412*	0.178	0.069
Missisquoi Bay	Missisquoi Bay DD	2.000	0.817	0.714	0.760	0.023	0.285	0.508	0.316	0.415	0.088
Missisquoi Bay	Missisquoi River	2.056	0.806	1.149	0.981	0.009	0.266	0.286	0.433	0.261	0.204
Isle La Motte	Isle La Motte DD	1.967	0.729	0.759	0.746	0.036*	0.024	0.084	0.076	0.077	0.069
Basin-wide		2.138	0.810	1.115	0.980	0.036	0.238	0.288	0.412	0.243	0.064

*The basin wide average of the HSG soil type was used here, as these loads were not included in the TMDL modeling.

Table A-2. Lake Memphremagog basin phosphorus loading rates for developed lands (kg/acre/year). Data from VT DEC (2017). WA = weighted average

Drainage Area	Developed Pervious (WA)	Impervious (WA)	Paved Roads	Unpaved Roads	Forest (WA)
Black River-headwaters to Seaver Branch	0.2426	0.8511	0.4622	2.0335	0.0297
Black River-Seaver Branch to Lords Creek	0.2674	0.9382	0.5094	2.2414	0.0327
Lords Creek	0.2613	0.9166	0.4977	2.1899	0.0319
Black River-Lords Creek to mouth	0.2651	0.9301	0.505	2.2221	0.0324
Barton River-headwaters to Roaring Brook	0.2035	0.7139	0.3876	1.7056	0.0249
Barton River-Roaring Branch to Willoughby River	0.1567	0.5498	0.2986	1.3136	0.0192
Willoughby River	0.1834	0.6432	0.3493	1.5368	0.0224
Barton River-Willoughby River to mouth	0.2305	0.8085	0.439	1.9317	0.0282
Clyde River-headwaters to Echo Lake stream	0.0852	0.2989	0.1623	0.7141	0.0104
Seymour and Echo Lakes	0.0266	0.0933	0.0507	0.2229	0.0033
Clyde River-Echo Lake stream to mouth	0.1507	0.5288	0.2871	1.2633	0.0184
Direct drainage-south end of Lake Memphremagog	0.2458	0.8622	0.4681	2.0598	0.03

Appendix B. BMP Performance Curve Data

Table B-1. Phosphorus removal rates from BMP performance curves. Data from US EPA (2010).

Depth of Runoff from Impervious Surfaces (inches)	0.1	0.2	0.4	0.6	0.8	1	1.5	2
Infiltration Basin 8.27 in/hr	59%	81%	96%	99%	100%	100%	100%	100%
Infiltration Basin 2.41 in/hr	46%	67%	87%	94%	97%	98%	100%	100%
Infiltration Basin 1.02 in/hr	41%	60%	81%	90%	94%	97%	99%	100%
Infiltration Basin 0.52 in/hr	38%	56%	77%	87%	92%	95%	98%	99%
Infiltration Basin 0.27 in/hr	37%	54%	74%	85%	90%	93%	98%	99%
Infiltration Basin 0.17 in/hr	35%	52%	72%	82%	88%	92%	97%	99%
Infiltration Trench 8.27 in/hr	50%	75%	94%	98%	99%	100%	100%	100%
Infiltration Trench 2.41 in/hr	33%	55%	81%	91%	96%	98%	100%	100%
Infiltration Trench 1.02 in/hr	27%	47%	73%	86%	92%	96%	99%	100%
Infiltration Trench 0.52 in/hr	23%	42%	68%	82%	89%	94%	98%	99%
Infiltration Trench 0.27 in/hr	20%	37%	63%	78%	86%	92%	97%	99%
Infiltration Trench 0.17 in/hr	18%	33%	57%	73%	83%	90%	97%	99%
Gravel Wetland	19%	26%	41%	51%	57%	61%	65%	66%
Wet Pond/ Constructed Wetland/ Biofiltration/ Sand Filter	14%	25%	37%	44%	48%	53%	58%	63%
Dry Pond	3%	6%	8%	9%	11%	12%	13%	14%
Grass Swale	2%	5%	9%	13%	17%	21%	29%	36%

Appendix C. **Stormwater Treatment Practice Types & Storage Volume Equations**

Table C-1. Stormwater treatment practice type storage volume equations. Table adapted from Tetra Tech (2016).

STP Type	Description	STP Calculator Curve	Method for Calculating Design Storage Volume (DSV)
Infiltration Trench	Provides storage of runoff using the void spaces within the soil/sand/gravel mixture within the trench for infiltration into the surrounding soils.	Infiltration Trench	DSV = void space volumes of stone and sand layers $DSV = (A_{trench} \times D_{stone} \times n_{stone}) + (A_{trench} \times D_{sand} \times n_{sand})$ $n = 0.33$
Subsurface Infiltration	Provides storage of runoff using the combination of storage structures and void spaces within the washed stone within the system for infiltration into the surrounding soils.	Infiltration Trench	DSV = storage volume of storage units and void space of backfill materials. Example for subsurface galleys backfilled with washed stone: $DSV = (L \times W \times D)_{galley} + (A_{backfill} \times D_{stone} \times n_{gravel})$ $n_{gravel} = 0.33$
Surface Infiltration	Provides storage of runoff through surface ponding (e.g., basin or swale) for subsequent infiltration into the underlying soils.	Surface Infiltration	DSV = volume of storage structure before bypass. Example for linear trapezoidal vegetated swale. $DSV = (L \times ((W_{bottom} + W_{top@Dmax})/2) \times D)$
Rain Garden/ Bioretention (no underdrains)	Provides storage of runoff through surface ponding and possibly void spaces within the soil/sand/washed stone mixture that is used to filter runoff prior to infiltration into underlying soils.	Surface Infiltration	DSV = Ponding water storage volume and void space volumes of soil filter media. Example for raingarden: $DSV = (A_{pond} \times D_{pond}) + (A_{soil} \times D_{soil} \times n_{soil\ mix})$ $n_{soil\ mix} = 0.33$
Rain Garden/ Bioretention (w/underdrain)	Provides storage of runoff by filtering through an engineered soil media. The storage capacity includes void spaces in the filter media and temporary ponding at the surface. After runoff passes through the filter media it discharges through an under-drain pipe.	Bioretention	DSV = Ponding water storage volume and void space volume of soil filter media. $DSV = (A_{bed} \times D_{ponding}) + (A_{bed} \times D_{soil} \times n_{soil})$ $n_{soil} = 0.33$
Gravel Wetland	Provides surface storage of runoff in a wetland cell that is routed to an underlying saturated gravel internal storage reservoir (ISR). Outflow is controlled by an orifice that has its invert elevation equal to the top of the ISR layer and provides retention of at least 24 hrs.	Gravel Wetland	DSV = pretreatment volume + ponding volume + void space volume of gravel ISR. $DSV = (A_{pretreatment} \times D_{Pretreatment}) + (A_{wetland} \times D_{ponding}) + (A_{ISR} \times D_{gravel} \times n_{gravel})$ $n_{gravel} = 0.33$ See (a) below.

STP Type	Description	STP Calculator Curve	Method for Calculating Design Storage Volume (DSV)
Porous Pavement with infiltration	Provides filtering of runoff through a filter course and temporary storage of runoff within the void spaces of a subsurface gravel reservoir prior to infiltration into subsoils.	Infiltration Trench	DSV = void space volumes of gravel layer $DSV = (A_{pavement} \times D_{stone} \times n_{gravel})$ $n_{gravel} = 0.33$
Porous pavement w/ impermeable underlining or underdrain	Provides filtering of runoff through a filter course and temporary storage of runoff within the void spaces prior to discharge by way of an underdrain.	Porous Pavement	Depth of Filter Course = D_{FC}
Sand Filter w/underdrain	Provides filtering of runoff through a sand filter course and temporary storage of runoff through surface ponding and within void spaces of the sand and washed stone layers prior to discharge by way of an underdrain.	Sand Filter	DSV = pretreatment volume + ponding volume + void space volume of sand and washed stone layers. $DSV = (A_{pretreatment} \times D_{preTreatment}) + (A_{bed} \times D_{ponding}) + (A_{bed} \times D_{sand} \times n_{sand}) + (A_{bed} \times D_{stone} \times n_{stone})$ $n = 0.33$
Wet Pond	Provides treatment of runoff through routing through permanent pool.	Wet Pond	DSV= Permanent pool volume prior to high flow bypass. See (a) below.
Extended Dry Detention Basin	Provides temporary detention storage for the design storage volume to drain in 24 hours through multiple outlet controls.	Dry Pond	DSV= Ponding volume prior to high flow bypass $DSV = A_{pond} \times D_{pond}$ (does not include pretreatment volume)
Grass Conveyance Swale	Conveys runoff through an open channel vegetated with grass. Primary removal mechanism is infiltration.	Grass Swale	DSV = Volume of swale at full design flow See (b) below.
Footnotes:			
DSV= Design Storage Volume = physical storage capacity			
L= length, W= width, D= depth at design capacity before bypass, n=porosity fill material, A= average surface area for calculating volume			
Infiltration rate = saturated soil hydraulic conductivity			

a. Storage Volume for Ponds and Wetlands

For wet ponds and gravel wetlands, there is typically a large outlet at or near the top of the outlet riser that allows larger storms to exit the practice quickly. Storage above that level is considered flood storage and should be excluded from credit calculations.

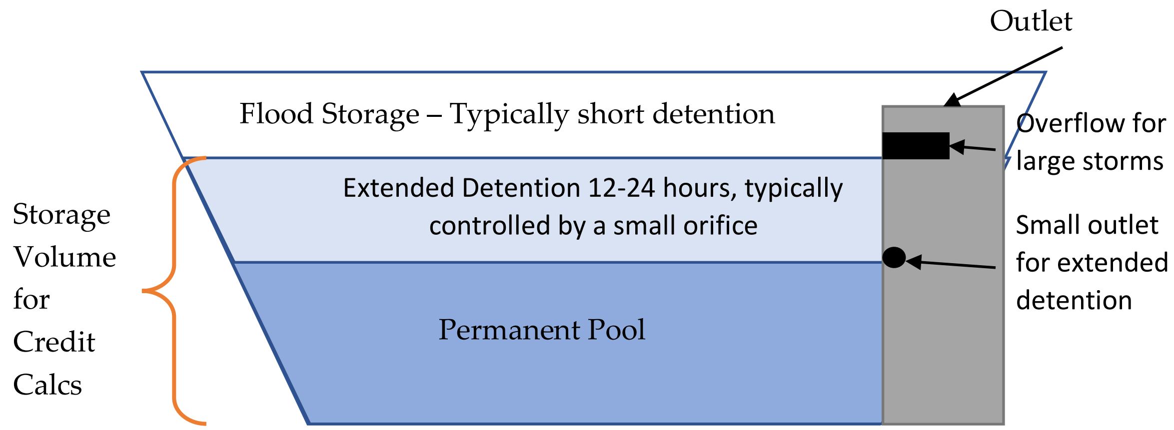
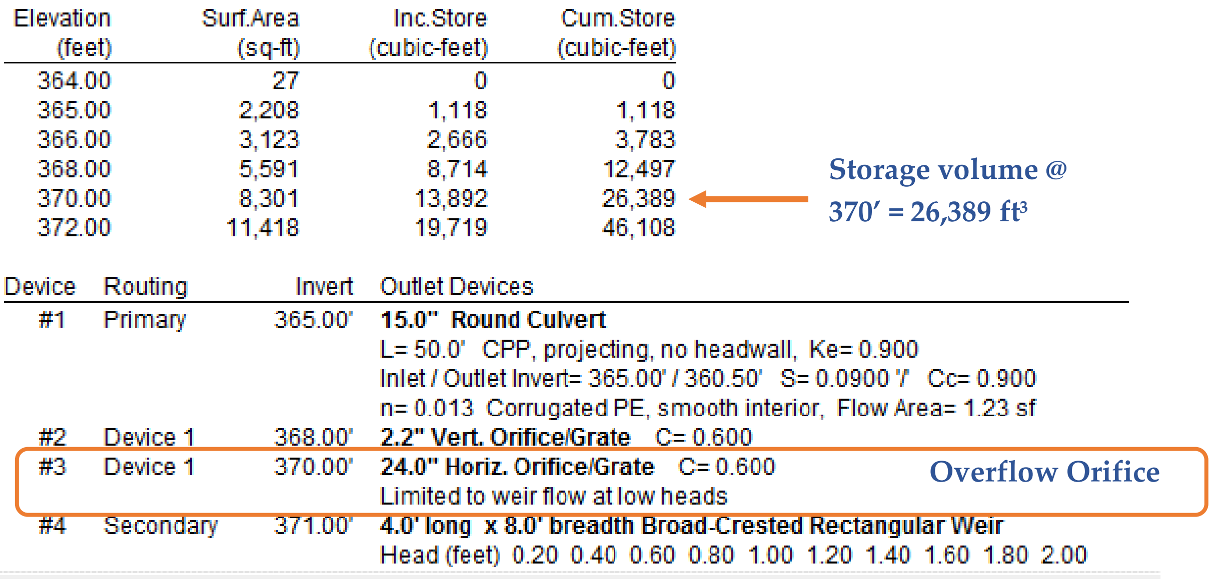


Figure C-1. Generalized schematic of a Wet Pond

Modeling documentation for the practice should include a stage vs. storage table that can be used to determine the appropriate volume for crediting.



```
Elevation      Surf.Area      Inc.Store      Cum.Store
   (feet)        (sq-ft)   (cubic-feet)   (cubic-feet)
   364.00             27              0              0
   365.00          2,208          1,118          1,118
   366.00          3,123          2,666          3,783
   368.00          5,591          8,714         12,497
   370.00          8,301         13,892         26,389
   372.00         11,418         19,719         46,108

Device  Routing      Invert   Outlet Devices
  #1    Primary     365.00'   15.0" Round Culvert
                              L= 50.0'  CPP, projecting, no headwall,  Ke= 0.900
                              Inlet / Outlet Invert= 365.00' / 360.50'  S= 0.0900 '/'  Cc= 0.900
                              n= 0.013  Corrugated PE, smooth interior,  Flow Area= 1.23 sf
  #2    Device 1    368.00'   2.2" Vert. Orifice/Grate    C= 0.600
  #3    Device 1    370.00'   24.0" Horiz. Orifice/Grate    C= 0.600
                              Limited to weir flow at low heads
  #4    Secondary   371.00'   4.0' long  x 8.0' breadth Broad-Crested Rectangular Weir
                              Head (feet)  0.20  0.40  0.60  0.80  1.00  1.20  1.40  1.60  1.80  2.00
```

Storage volume @ 370′ = 26,389 ft^3

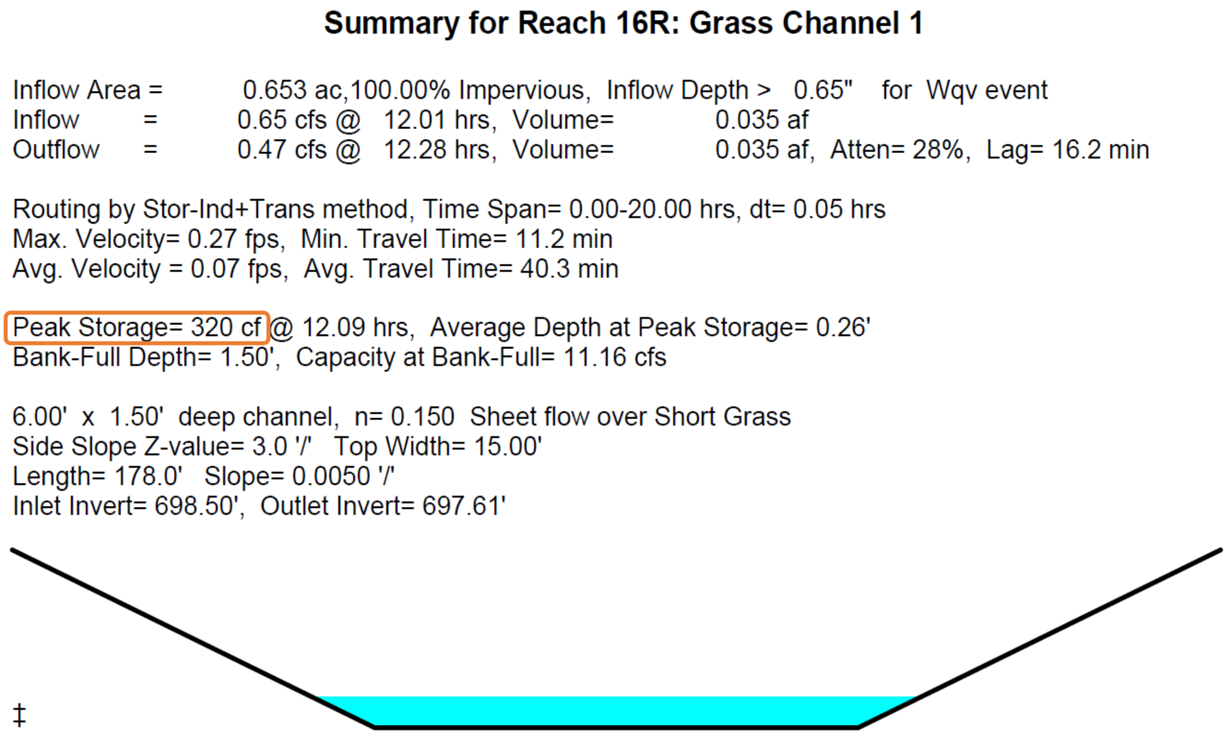
Overflow Orifice

Figure C-2. Storage volume determination from a HydroCAD summary.

Many ponds built prior to the adoption of the 2002 Vermont Stormwater Management Manual were designed for peak flow attenuation and have neither a permanent pool nor extended detention. Ponds lacking these features are not assigned a phosphorus credit as they do not provide significant treatment.

b. Storage Volume for Grass Channels

Grass channels were a popular treatment practice under the 2002 Vermont Stormwater Management Manual (VSMM). Grass channels were typically sized to provide treatment for the water quality storm, which was the 0.9″ storm under the 2002 VSMM. Grass channel typically have volume to convey large storms but credit calculations should be based on the peak volume of water in the swale during the water quality storm.



```
                Summary for Reach 16R: Grass Channel 1

Inflow Area =      0.653 ac,100.00% Impervious,  Inflow Depth >  0.65"   for  Wqv event
Inflow      =      0.65 cfs @   12.01 hrs,  Volume=         0.035 af
Outflow     =      0.47 cfs @   12.28 hrs,  Volume=         0.035 af,  Atten= 28%,  Lag= 16.2 min

Routing by Stor-Ind+Trans method, Time Span= 0.00-20.00 hrs, dt= 0.05 hrs
Max. Velocity= 0.27 fps,  Min. Travel Time= 11.2 min
Avg. Velocity = 0.07 fps,  Avg. Travel Time= 40.3 min

Peak Storage= 320 cf @ 12.09 hrs,  Average Depth at Peak Storage= 0.26'
Bank-Full Depth= 1.50',  Capacity at Bank-Full= 11.16 cfs

6.00'  x  1.50'  deep channel,  n= 0.150  Sheet flow over Short Grass
Side Slope Z-value= 3.0 '/'   Top Width= 15.00'
Length= 178.0'   Slope= 0.0050 '/'
Inlet Invert= 698.50',  Outlet Invert= 697.61'
```

Figure C-3. HydroCAD summary of a grass channel during the water quality storm event.

Appendix D. Generalized Phosphorus Reduction Efficiencies Applied for Structural STPs

Table D-1. Generalized phosphorus reduction efficiencies applied to structural STPs in the 2018 Clean Water Investment Report and the 2019 Clean Water Performance Report. Generalized phosphorus reduction efficiencies, used when there is inadequate practice sizing data, are based on typical practice sizes designed to meet the water quality standard per the Vermont Stormwater Management Manual.

Practice Type	Tier	Performance Curve	Generalized Phosphorus Reduction Efficiency	
			0.9" (2002)	1" (2017)
Infiltration Basin	Tier 1	Surface Infiltration	94%	95%
Infiltration Other	Tier 1	Infiltration Trench	87%	90%
Infiltration Trench	Tier 1	Infiltration Trench	87%	90%
Dry Swale Infiltrating	Tier 1	Surface Infiltration	91%	93%
Bioretention Infiltrating	Tier 1	Surface Infiltration	91%	93%
Surface Sand Filter Infiltrating	Tier 1	Infiltration Trench	87%	89%
Non-Rooftop Disconnection	Tier 1	Disconnection	55%	57%
Rooftop Disconnection	Tier 1	Disconnection	55%	57%
Gravel Wetland	Tier 2	Gravel Wetland	59%	61%
Bioretention Under-drained	Tier 3	Biofiltration	45%	46%
Sand Filter Underdrain	Tier 3	Biofiltration	67%	68%
Surface Wetland	Tier 3	Wet Pond	51%	53%
Wet Pond	Tier 3	Wet Pond	51%	53%
Dry Detention Pond	N/A	Dry Pond	12%	12%
Environmentally Sensitive Rural Development	Not 2017 VSMM	Disconnection/ Grass Channel	34%	38%
Grass Channels	Not 2017 VSMM	Grass Channel	19%	19%