

# Review of Stormwater Phosphorus Characteristics and Treatment for New Development in the New York City Watershed

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## I. Executive Summary

This report addresses the following question: “Can treated stormwater from a development project proposed at an undeveloped site (e.g. forest, meadow) be expected to achieve no net increase in total phosphorus (TP) loading?” The short answer is “highly unlikely.” This report also evaluates the effectiveness of certain stormwater controls for new development projects in the New York City Watershed and provides recommendations for improvements that can be implemented through the 2017 Filtration Avoidance Determination (FAD).

Stormwater regulations of the New York City Department of Environmental Protection (DEP) do not require applicants to perform phosphorous loading analyses which would ensure that effluents from proposed development projects do not increase phosphorus discharges, compared to pre-development levels.<sup>1</sup> This presents a particular difficulty for the City’s Croton system reservoirs that do not currently meet water quality standards due to eutrophic conditions from excessive phosphorus discharges within their watersheds. Moreover, phosphorous discharges within the Delaware system reservoirs can also contribute to this problem in Croton system reservoirs. Water from the Delaware System’s Rondout reservoir is fed by the other Delaware system reservoirs (the Cannonsville, Neversink, and Pepacton) and can travel through the Delaware Aqueduct into the West Branch Reservoir and then into the Croton system’s eutrophic Croton Falls, Muscoot, and New Croton reservoirs.

As discussed below, even when stormwater controls are properly designed and implemented, we can generally expect a net increase in phosphorus discharges from new development. To address this problem, I recommend that sponsors of development projects be required to establish that their planned stormwater controls would achieve no net increase in phosphorus discharges. TP and total suspended solids (TSS) are usually closely correlated, along with some metals. Therefore, removal of TP in sedimentation ponds or wetlands will also result in the removal of about half the TSS. Metals would be removed somewhat less than the TSS (lead the most, copper and zinc less). Infiltration controls (with no underdrains) would reduce all pollutants at the same rate, as the infiltrating water removes all pollutants from the surface runoff.

Recent research has shown that some of the stormwater controls allowed by DEP regulations -- grassed filter strips, grass swales, and bioretention systems – can actually increase phosphorus concentrations in stormwater. These controls can therefore lead to increased phosphorus discharge loading (concentrations times runoff volumes).<sup>2</sup> Therefore, the use of

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1 This is also true for New York State Department of Environmental Conservation (DEC) permits, but the subject of this study is stormwater policies within the New York City Watershed within the context of potential improvements by DEP pursuant to the 2017 FAD.

2 See footnote 1 above.

these controls needs to be carefully evaluated to ensure that increases in phosphorus concentrations are offset by runoff volume reductions, in addition to meeting other control objectives.

## **II. Can We Expect No Net Increase in Phosphorus Post-Development?**

We address whether pre-development total phosphorus (TP) stormwater load at a forested or meadow site can be matched after site development. One way to evaluate whether there is a net increase in TP load at a development site is to compare pre- versus post-development TP discharge loads. Load is calculated by multiplying the TP concentration by the runoff volume. Achieving no net increase in TP occurs when the estimated pre-development TP load is not exceeded by the estimated post-development TP load. This can be accomplished by reducing phosphorous concentration and/or runoff volume. Conversely, if the pre-development TP load is less than the post-development load, stormwater containing additional TP will leave the site, and there will be a net increase in TP.

The findings presented in this report indicate there are no conventional stormwater controls alone or in series that consistently provide the large reductions in TP concentrations necessary to match a pre-development concentration goal of 150 micrograms per liter ( $\mu\text{g/L}$ , or parts per billion), the pre-development TP concentration value adopted by New York for “forest” land use.<sup>3</sup> In addition, although many infiltration controls provide runoff volume reductions, runoff volume can increase as much as 5 to 20 times with development<sup>4</sup>. The benefits of stormwater infiltration controls on runoff volume reductions are highly dependent on site conditions, and the size and design of the stormwater control. Reducing large increases in runoff to pre-development levels is also very difficult.

Based on the analyses presented in this report, TP load almost always increases post-development. It is highly unlikely that treated stormwater from a development project, proposed at an undeveloped forest or meadow site, will be able to achieve no net increase in TP loading for all rain conditions using typical stormwater treatment technologies and site development characteristics.

This report summarizes pre- and post-development TP concentrations, the performance of stormwater controls for TP reductions, and volume reductions, from the literature. An example calculation using a continuous model quantifies the reduction goals needed to meet the TP pre-development load criterion. Several appendices are also included with this report to support the analyses and conclusions. Appendix A provides an analysis of TP data from the National Stormwater Quality Database, Appendix B summarizes effluent TP concentrations from stormwater controls as presented in the International BMP Database, Appendix C presents state regulations restricting the use of TP in fertilizers and laundry detergents, and Appendix D presents information for a number of models that can be used to

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<sup>3</sup> See January 20, 2012 letter from Robert Capowski of the New York Department of Environmental Conservation (DEC) concerning the Retrofit Program Annual Update and also from the East of Hudson Watershed Corporation “Stormwater Retrofit Project Design Manual” Revision: 1, dated March 5, 2015.

<sup>4</sup> National Research Council (NRC), Committee on Reducing Stormwater Discharge Contributions to Water Pollution, National Academy of Science. *Urban Stormwater Management in the United States*. ISBN: 13: 978-0-309-12539-0. National Academies Press, Washington, D.C. 2009, 598 pages.

evaluate TP conditions and control in urban areas. Appendices E and F show the modeling results for development projects in the New York City Watershed, comparing pre- and post-development total phosphorus discharges for a proposed residential project (Hidden Meadow) and a proposed redevelopment commercial project (Costco). The model results demonstrate that stormwater controls for those sites were unable to achieve no net increase in phosphorous loadings. While the projects also treated offsite stormwater, not enough was treated to prevent a net increase. Therefore, additional offsite stormwater treatment should occur to achieve a no net increase.

Stormwater at development sites can become contaminated during and after construction activities. Excavation and extensive grading practices during construction often expose large swaths of native soils, making them susceptible to erosion. Rainfall and stormwater runoff can transport eroded soil particles with attached pollutants (possibly including pathogens) and dissolved pollutants from construction sites to receiving waters. Runoff containing phosphorus entering a body of fresh water, can stimulate algae growth and lead to the formation of algae blooms, which degrade water quality. Water quality can also become compromised as turbidity, total suspended solids, and conductivity increase. Post construction, developed land can also contribute a variety of pollutants to stormwater, including: contaminants associated with building materials, such as galvanized metals and treated wood, along with fertilizers, pesticides, and petroleum from automobile use and landscape maintenance, and nutrients and bacteria from pet and urban wildlife feces.

### ***1. Concentration***

Forest and meadow ecosystems are generally considered pre-development conditions in New York. While New York has adopted a pre-development TP concentration value of 150 µg/L for “forest” land use, it has not adopted a reference concentration for “meadow” land use. The 1996 Terrene Institute’s “A Watershed Approach to Urban Runoff” presents a TP concentration of 110 µg/L for runoff from both “forest” and “rural open land” (meadow). This report uses a pre-development TP concentration value of 150 µg/L for both forest and meadow as a reference value. Meeting a 110 ug/L TP goal would be even more difficult than the 150 ug/L goal discussed in this report.

Table 1 shows average total phosphorus concentrations associated with both pre-development meadow and forest conditions compared to post-development TP concentrations without stormwater controls in low and medium density residential areas and commercial areas.

**Table 1: TP Average Concentrations in Stormwater in Pre- and Post-Development Conditions**

Source	Pre-Development Conditions		Post-Development Conditions		
	Meadow/rural open land runoff (TP $\mu\text{g/L}$ )	Forest runoff (TP $\mu\text{g/L}$ )	Low density residential runoff (TP $\mu\text{g/L}$ ; 2 ac lots)	Medium density residential runoff (TP $\mu\text{g/L}$ ; 0.25 ac lots)	Commercial area runoff (TP $\mu\text{g/L}$ )
New York guidance (2012)	n/a	150	410	410	340
East of Hudson Watershed Corp. Retrofit Manual (2015)	n/a	150	410	410	340
Terrene Institute (1996)	“Rural open land”: 110	110	520	520	330
National Stormwater Quality Database (NSQD), ver. 4 (East Coast regional data)	n/a	n/a	400	400	220
WinSLAMM model using East Coast calibration data set (calibrated using NSQD East Coast data)	n/a	n/a	390 to 620 (depends on site soils)	390 to 550 (depends on site soils)	Strip commercial: 190 to 210 (minor effects due to site soils)

No conventional stormwater controls can likely provide the reductions in TP concentrations necessary to consistently achieve a no net increase goal of 150  $\mu\text{g/L}$ . Listed below are typical stormwater controls and the percent of precipitation events expected to exceed the no net increase TP concentration goal of 150  $\mu\text{g/L}$ , as reported in the International Stormwater Best Management Practices (BMP) Database, which includes stormwater pollutant removal data from different land uses (see Appendix B for a complete summary). Table 2 below shows the effectiveness of commonly used controls in meeting that 150  $\mu\text{g/L}$  criterion, ranked from least to most effective:

**Table 2: Ranking the Effectiveness of Typical Stormwater Controls at Reducing Total Phosphorus (summarized from the International BMP Database) From Least Effective to Most Effective**

Typical Stormwater Controls	Approximate Percentage of Precipitation Events Expected to Exceed a Total Phosphorus Effluent Concentration of 150 µg/L
oil/grit separators and baffle boxes	75-95%
dry detention ponds	50 – 75%
grass filter strips, grass swales, & bioretention systems	
manufactured device physical	
wet channel	50%
inlet inserts	25 – 50%
physical treatment with volume control	
wetland basin	
wetland basin & retention pond combination	
media filters	25%
porous pavement	
biological filtration	5 – 25%
sand filtration	5%
multi-process (treatment trains)	less than 5%

None of the stormwater control devices listed above have been shown to consistently meet the pre-development 150 µg/L TP concentration goal with no exceedances. Note that grass filter strips, grass swales, and bioretention systems perform relatively poorly. In fact, TP concentrations increase during many precipitation events with these controls, likely due to erosion of soils having high TP content in the vegetated areas or from TP leaching from compost or other biofilter media material having high TP content. Nevertheless, these controls are authorized for use in the New York City Watershed.

The most effective TP control is the multi-process treatment train, which likely meets the criterion for more than 95% of precipitation events. Sand filters appear to be effective about

95% of the time. DEP regulations require the use of multi-process treatment trains under some conditions for portions of development sites having relatively large impervious areas.<sup>5</sup>

While chemical controls are not included in the International Stormwater BMP Database, limited data indicates that they can be very effective at reducing TP concentrations. However, achieving 100% compliance with pre-development site conditions using chemical controls cannot be guaranteed, as chemical dosage rates, mixing, and sludge settling, are usually designed and operated based on a specified (“design”) flow condition, and typical stormwater flow and quality variations increase operational complexity.

It is not likely that any conventional stormwater control can meet pre-development TP concentrations under all conditions. Treatment trains using multiple processes in sequence have been developed to provide large reductions in TP concentration and achieve high levels of compliance, but not 100%. Therefore, with TP concentrations likely to increase with development, greater runoff volume reductions will be needed to meet the no net increase TP discharge (load) objective.

## ***2. Volume Reductions***

The control of runoff volume (and associated runoff energy) associated with urban land development has become very important in recent years due to a better understanding of: 1) the causes of accelerated erosion, and 2) the adverse effects of stormwater on aquatic life in receiving waters. In general, development causes large increases in runoff volume, so to achieve no net increase in TP loads, greater decreases in TP concentrations need to be realized. Monitored sites indicate that runoff volume can increase as much as 5 to 20 times with development. If adequate runoff volume reductions are not employed during new site development, even greater concentration reductions would be needed. For example, the post-development TP effluent concentration goal of 150 µg/L might need to be reduced to less than 30 µg/L if site runoff volumes are increased by even 5 times, which is a very difficult concentration goal to achieve. Therefore, runoff volume reductions should be an important component of stormwater management strategies.

Runoff reduction efforts may be restricted by site conditions or development features. For example, specific site conditions such as soil type and steep slopes can greatly influence stormwater runoff characteristics and stormwater management selections at a development site. In general, precipitation can completely percolate through uncompacted, sandy soils for most rains (Natural Resources Conservation Service [NRCS] hydrologic soil groups A & B), whereas rainwater often runs across silty and clayey soils (NRCS hydrologic soil groups C & D) as sheetflow, and at times forms pools. When slopes are steep, runoff velocities increase

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<sup>5</sup> See Watershed Rules and Regulations, §18-39(c)(6): “If an activity requiring a stormwater pollution prevention plan will result in impervious surfaces covering twenty percent (20%) or more of the drainage area for which a stormwater management practice is designed, the stormwater pollution prevention plan shall provide for stormwater runoff from that drainage area to be treated by two different types of stormwater management practices in series, except that only one stormwater management practice is required if either: (i) the stormwater management practice provided is a stormwater infiltration practice; or (ii) the activity requiring a stormwater pollution prevention plan is in the West of Hudson watershed within a village, hamlet, village extension, or area zoned for commercial or industrial uses or in the East of Hudson watershed within a Designated Main Street Area.

and available time for infiltration decreases. Development features, especially impervious surfaces, such as roofs and paved parking areas, and typical soil compaction also increase runoff volumes.

Historically, dry stormwater detention ponds (as defined in the International Stormwater BMP database) have been the preferred method to reduce runoff rates and energy. However, this stormwater practice has little effect on runoff volume, unless significant infiltration also occurs at the treatment location. As noted previously, dry detention ponds also provide relatively small TP concentration reduction benefits. However, they can help reduce runoff velocity and associated energy and subsequent erosion.

A number of strategies have been developed to reduce runoff volume at source areas. Stormwater controls incorporating treatment trains with infiltration as a feature are one example that can provide significant stormwater runoff volume and pollutant concentration reductions. However, not all stormwater controls reduce both runoff volume and TP concentrations. For example, although bioretention facilities, rain gardens, and grass swales reduce runoff volume, they can also increase TP concentrations. TP increases originate from a variety of sources, such as exposure to fertilizers, organic materials (e.g. decaying flowers and leaves), and soils containing high levels of TP. In addition, bioretention facilities commonly incorporate compost and/or topsoil to serve as plant growth media and to retain a variety of pollutants. These stormwater controls have been shown to cause significant TP releases. To address this issue, some states, such as Wisconsin, are now recommending that sand and other inert materials (such as peat) be used instead of organic amendments containing elevated TP (such as compost) and topsoil.

As shown below, meeting pre-development runoff volume conditions is only possible with very careful planning at the design stage, and subsequent extensive use of on-site infiltration practices.

### ***3. Example: Post-Development Discharge Loading Calculations and Necessary Mass Reductions to Meet Pre-Development Conditions***

There are a number of models available for calculating TP in post-development discharges, ranging from simple, single event calculations to continuous multi-event models. In general, simple models are based on a single average condition, such as average annual rainfall, or a peak condition, such as a single design storm. Calculating the discharge loads for a single event and assuming it accurately reflects long-term conditions can be misleading, as the estimated load reductions associated with a single large (design) event is not likely to be the same as the load reductions based on the long-term sum of loads for many events. Continuous evaluations of the flows used to calculate the long-term sum of loads from all events consider the full range of conditions and more accurately reflect the expected stormwater control benefits compared to single event or average calculations. This approach also enables exceedance calculations to be made and provides a better understanding of the conditions causing failures. This information is very helpful to a regulatory agency and can be used to develop realistic performance goals, instead of applying criterion having no allowable exceedances under any conditions.

Continuous long-term models consider a wide variety of rain conditions, including varying rainfall amounts, intensities, and inter-event periods over a number of years. It allows for the consideration of a wide range of rain and antecedent moisture conditions, reflecting periods of both lower and higher than normal rainfall. Utilizing a continuous long-term model increases result reliability and addresses some of the assumptions made in the single event calculations. However, continuous long-term models often require more data than single event models and interpretation of model results may be more complex.

Correctly interpreting stormwater quality data depends upon calibrated and verified models, which rely on extensive local data. Without these data, the calculated results have greater uncertainty.

The following example uses a continuous, long-term, regionally calibrated stormwater model called WinSLAMM (Windows Source Loading and Management Model). See Appendix D for more information about this and other models. The demonstration model described below is for Albany, NY. It is used to identify sources of urban stormwater pollutants and to evaluate the efficiency of treatment control practices. In addition, in section 4 below, we evaluate two development projects in the New York City Watershed, one multi-family residential and the other commercial.

The following calculations use a typical long-term rainfall series (more than 50 years of recorded rains) for Albany, NY. As discussed previously, pre-development loading calculations are based on a TP concentration of 150 µg/L. The curve number (CN) values associated with the pre-development land uses are applied to each of the 6,148 rains events recorded during this period to obtain pre-development runoff volumes. The 150 µg/L TP concentration value is then applied to each of these rains. Appropriate unit conversions are then used to calculate the pre-development TP load. This value is divided by 51.65 years (the total rain period used in these analyses) and the number of acres used in the calculations to obtain the long-term average per acre annual load associated with pre-development conditions. These calculations were conducted for each of the four standard NRCS hydrologic soil groups (A, B, C, and D), representing sandy to clayey soil conditions.

Post-development TP loads associated with low and medium density residential projects and commercial land use were based on typical land development conditions.<sup>6</sup> The expected post-development TP concentrations and unit area loads (concentrations times runoff volumes) were calculated using a calibrated and verified version of the WinSLAMM stormwater model for East Coast conditions. The same long-term rain file was used and the TP discharge loads from each of the individual rains were summed and divided by the number of years and areas to obtain the unit area annual TP discharge loads for these post-development conditions (pounds/acre/year).

The pre- and post-development unit area TP loads were compared and the reduction goals required to meet the pre-development conditions were then calculated.

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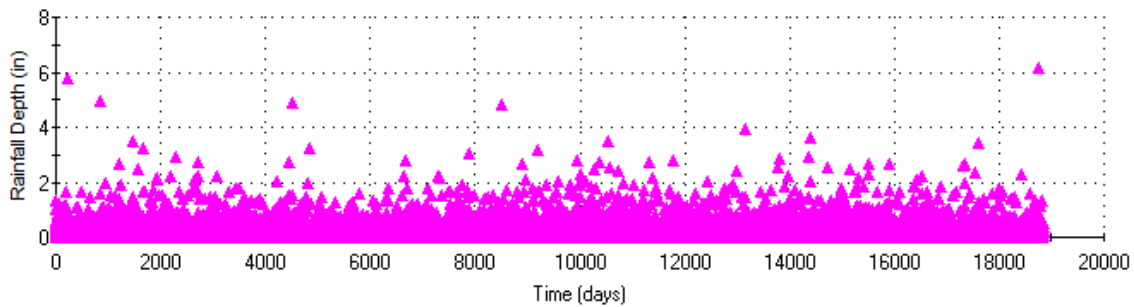
[http://rpitt.eng.ua.edu/Publications/4\\_Stormwater\\_Characteristics\\_Pollutant\\_Sources\\_and\\_Land\\_Development\\_Characteristics/Land\\_development\\_characteristics/Standard%20Land%20Use%20file%20descriptions%20final%20April%2018%202011%20for%20EPA%20Cadmus.pdf](http://rpitt.eng.ua.edu/Publications/4_Stormwater_Characteristics_Pollutant_Sources_and_Land_Development_Characteristics/Land_development_characteristics/Standard%20Land%20Use%20file%20descriptions%20final%20April%2018%202011%20for%20EPA%20Cadmus.pdf)

The following information provides the basis for the WinSLAMM model calculations:

- Rainfall Conditions

Albany, NY; 5/7/1948 to 12/20/99 (51.65 years), as recorded by NOAA and obtained from EarthInfo CDRoms. Albany rains were used for these initial analyses due to the availability of complete rainfall information for a long duration. During this period, there were 6,148 rains, totaling 1,851.27 inches, resulting in an average of 35.84 inches per year. The average rain depth was 0.3 inches, with a peak recorded rain of 6.13 inches. The following figure presents a dot time series diagram illustrating these rains over this period of time. The rains are reasonably consistent in their pattern, but with some periods having slightly less rain and others having slightly more rain.

**Figure 1: 51.65 Years of Rainfall for Albany, NY**



- Total Phosphorus Concentrations (see fourth row of Table 1 above)

WinSLAMM was used to calculate expected post-development TP concentrations, based on the regional calibrations reflecting the National Stormwater Quality Database (NSQD, see Appendix A). Appendix A describes the NSQD and includes regional data applied to these analyses.

- Runoff Values

WinSLAMM was used to calculate the runoff volumes for the 51.65 years of actual recorded rains at Albany for both pre-development and post-developed conditions. Corresponding CN values from WinTR55 were used for the pre-developed WinSLAMM calculations shown in Table 3.

**Table 3: Pre-Development Natural Resources Conservation Service (NRCS) Curve Numbers for Pastures and Woods**

Hydrologic soil conditions:	A (sandy, loamy sand, or sandy loam)	B (silt loam or loam)	C (sandy clay loam)	D (clay loam, silty clay loam, sandy clay, silty clay, or clay)
Pasture, Grassland, or Range (fair condition, as defined in TR55)	49	69	79	84
Woods (fair condition, as defined in TR55)	36	60	73	79

These curve numbers were then applied to rainfall values to calculate the pre-development TP discharge loads. WinSLAMM applied these constant CN values for all rains in this multi-year series to determine average annual runoff volumes. WinSLAMM also multiplied the runoff volume for each rain event by the 150 µg/L TP concentration, summed these values, and then calculated the annual average unit area TP discharges. These results are shown on Table 4 for the two pre-development conditions and the range of hydrologic soil conditions:

**Table 4: Pre-Development Hydrologic & Total Phosphorus Load Summary**

NRCS Hydrologic Soil Condition:	Pasture, Grassland, or Range (fair condition)				Woods (fair condition)			
	A	B	C	D	A	B	C	D
Corresponding NRCS CN values:	49	69	79	84	36	60	73	79
Calculated total runoff (ft <sup>3</sup> /acre/year)*	427	3,910	10,600	17,300	61	1,510	5,840	10,600
inches runoff/year	0.12	1.08	2.91	4.77	0.02	0.42	1.61	2.91
Runoff Coefficient (Rv), flow-weighted average value (runoff/rainfall depth ratio; fraction of total rainfall occurring as direct runoff)	0.0033	0.030	0.081	0.13	0.0005	0.012	0.045	0.081
TP concentration (µg/L)	150	150	150	150	150	150	150	150
TP load (lb/acre/year)	0.004	0.037	0.099	0.16	0.001	0.014	0.055	0.099
NY DEC (1993)** (lb TP/ac/yr)	pasture: 0.3 for hydrologic soil groups A & B, & 0.5 for HSG C & D. idle land: 0.1 for HSG A & B, & 0.2 for HSG C & D.				forest land: 0.1			

\* runoff volume calculated with WinSLAMM using the CN pre-development conditions for all rains in the 50.65 year period.

\*\* NY DEC “Reducing the Impacts of Stormwater Runoff from New Development” 1993 (Table 9, p. 40).

The runoff volumes vary greatly depending on the soil characteristics, and the calculated pre-development values (with constant CN and TP concentration for all rains) presented here are somewhat smaller than presented by the NY DEC (1993).

WinSLAMM calculated post-development TP concentrations and annual loads for low and medium density residential areas and strip commercial areas. The model was calibrated using East Coast data obtained from the National Stormwater Quality Database (as noted above and described in Appendix A), and its results are shown below:

**Table 5: Post-Development Hydrologic & Total Phosphorus Load Summary**

	low density residential (2 acre lots)			medium density residential (no alleys, & 0.25 acre lots)			strip commercial		
Soil texture (normal compaction):	sandy	silty	clayey	sandy	silty	clayey	sandy	silty	clayey
Calculated runoff (ft <sup>3</sup> /acre/yr)*	14,100	18,800	21,500	26,000	30,200	33,600	89,200	89,700	90,800
Rv	0.11	0.14	0.16	0.2	0.23	0.26	0.69	0.69	0.7
TP conc (mg/L)	0.39	0.57	0.62	0.39	0.53	0.55	0.19	0.20	0.21
TP load (lb/ac/yr)	0.34	0.67	0.79	0.64	1.00	1.16	1.06	1.15	1.20
NY DEC (1993)** (lb TP/ac/yr)	Estate (10 ac lots): 0.3 Large Lots (1 ac lots): 0.6 for hydrologic soil groups A & B, & 0.8 for HSGs C & D			Medium Density Residential (4 units/ac): 0.9 for HSG A & B, & 1.1 for HSG C & D			Shopping Center: 1.6; & Central Business District: 2.7		

\* runoff volume calculated using WinSLAMM’s calibrated runoff files for East Coast conditions for all rains in the 56+ year period.

\*\* NY DEC “Reducing the Impacts of Stormwater Runoff from New Development” 1993 (Tables 4 & 9).

The calculated annual unit area TP discharges for these post-developed conditions are very similar to the values reported by NY DEC (1993). As noted in Table 5, the runoff volumes and corresponding TP loads assume normally compacted urban soils. In general, county soil maps are based on pre-development meadow and forest conditions and do not reflect the compaction or massive disturbance (cutting and filling) that soils undergo during development. More severely compacted soils would result in increased runoff and TP discharged loads.

Table 6 summarizes the calculated TP loads for different land uses, along with the reductions required to meet pre-development TP conditions.

**Table 6: TP Annual Loads Comparison Summary and TP Percentage Reduction Needed**

1. Load reductions	2. Average pasture/forest TP annual loads (lbs/ac/yr)	3. Average low density residential TP annual loads (lbs/ac/yr)	4. Low density resid. % TP reduc. Needed	5. Average medium density residential TP annual loads (lbs/ac/yr)	6. Medium density resid. % TP reduc. needed	7. Strip commercial TP annual loads (lbs/ac/yr)	8. Strip commercial % TP reduc. needed
sandy (HSG A & B)	0.014	0.34	96	0.64	98	1.06	99
silty (HSG C)	0.077	0.67	89	1.0	92	1.15	93
clayey (HSG D)	0.130	0.79	83	1.16	89	1.2	89

Key: To Determine Column 4:  $100 - (\text{Column 2}/\text{Column 3})$ ;  
 To Determine Column 6:  $100 - (\text{Column 2}/\text{Column 5})$ ;  
 To Determine Column 8:  $100 - (\text{Column 2}/\text{Column 7})$ .

The necessary reductions in annual unit area TP loads (Columns 4, 6, & 8) are shown to be very large (83 to 99%, depending on the soil and development conditions), and would be very difficult to meet without extensive and very effective concentration and runoff volume controls.

*Summary of the Example:*

Alternative controls for a broad range of site and rainfall conditions should be evaluated using a continuous long-term simulation model to select those that best meet the pre-development goals for specific site conditions. Calculations based on a single precipitation event can be misleading, as the estimated load reductions associated with a single large event are not likely to be the same as the load reductions based on the annual sum of loads (for all events added). The calculated benefits of the controls will therefore likely be different for these different calculation methods. Continuous calculations made using a continuous stormwater quality model consider a wide variety of rain conditions, including varying rainfall amounts, intensities, and inter-event periods. Some combinations of rain conditions result in lower, while others result in higher, than expected discharge amounts. In addition, a continuous model can consider site specific development characteristics, including, for example, soil compaction and depth to groundwater, which can be used to identify the best set of candidate stormwater controls.

The example calculations shown in this report consider a range of pre- and post-development conditions. The long-term continuous calculations resulted in a range of expected levels of flow and/or TP concentration reductions needed. These are all very large, especially when compared to the literature summaries for TP reduction performance for a wide range of stormwater controls that were summarized in Table 1.

#### **4. Case Studies of Proposed Development Projects in the New York City Watershed**

Analyses of the Hidden Meadow and Costco development projects in the New York City Watershed demonstrate that on-site stormwater controls were unable to achieve no net increase in phosphorous loadings. Rather, controls of offsite stormwater were incorporated in an attempt to achieve that objective.

The Hidden Meadow development is about 35 acres in size, with about 10 acres developed in multi-family residences, parks, and roadways and 5 acres of undeveloped area that drains onto the developed area. The stormwater quality model, WinSLAMM (version 10.3), was used to calculate the expected post-development stormwater quality (focusing on total phosphorus) for this typical residential development. As noted, about 15 acres of the 35 acre site was developed, with the remaining 20 acres similar to the predevelopment conditions. There are many stormwater controls used at the site. Porous pavement driveways and backyard decks (which also receive portions of roof runoff) and rain gardens are used throughout the site. A large grass swale drains an upgradient area along with backyard areas for some of the units. A large bioretention area located along the main road which also receives some of the site area runoff. Another large bioretention area at the recreation field receives runoff from several buildings and adjacent areas, while a large pond receives runoff from much of the area (most already receiving some prior treatment).

Since WinSLAMM does not calculate snowmelt runoff, the following estimate was used to predict snowmelt total phosphorus discharges. The estimated runoff amount from this developed area during snowmelt events (when infiltration practices are not likely to be functioning) is estimated to be about 55,900 ft<sup>3</sup>/yr (based on the precipitation amount during the winter season. This assumes the same runoff responses for the winter rains as for similar sized non-winter rains). A reasonable value for snowmelt total phosphorus concentrations is 0.23 mg/L, as measured during extensive snowmelt water quality monitoring in residential and commercial areas in Toronto<sup>7</sup>. The estimated snowmelt total phosphorus yield was calculated by multiplying the estimated snowmelt runoff volume by the concentration.

As shown on the summary table below, the total phosphorus load after development is expected to increase by about 0.22 pounds per year compared to the pre-developed conditions, even with the extensive stormwater controls at the site and despite the project's treatment of stormwater originating offsite. Detailed information for this analysis is included in Appendix E.

The Costco site is a redeveloped area that was originally occupied by a plant nursery/lawn mower service center, two residential properties, a former motel and a fence company. The redeveloped area is comprised of large parking areas and a large Costco building, along with several outbuildings. The total area is about 24 acres. The pre- and post-redeveloped site areas were evaluated using the stormwater quality model, WinSLAMM

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<sup>7</sup> Pitt, R. and J. McLean. *Humber River Pilot Watershed Project*, Ontario Ministry of the Environment, Toronto, Canada. 483 pgs. June 1986.

(version 10.3), to calculate stormwater total phosphorus discharges for this typical redevelopment commercial project. There were two stormwater controls used at the site before redevelopment, a wet pond/wetland area and a grass swale. After redevelopment, many site stormwater controls were used at the site, including grass swales, wet ponds/wetlands, and large infiltration chambers, along with several hydrodynamic devices.

Snowmelt runoff for the pre-and post-developed conditions were calculated in a similar manner as described above for Hidden Meadow. The estimated runoff amount from the pre- and post- redeveloped area during snowmelt events is estimated to be about 135,000 and 385,500 ft<sup>3</sup>/yr, respectively. A reasonable value for snowmelt total phosphorus concentrations is 0.23 mg/L, as measured during extensive snowmelt water quality monitoring in Toronto residential areas (Pitt and McLean 1986). The Costco site incorporates large underground infiltration chambers that are expected to receive snowmelt runoff. However, directing snowmelt to the underground infiltration chambers will subject it to potentially high loads of deicing salts. Snowmelt, containing sodium from deicing salts, can react with clay in native soils on site and can cause sodium adsorption ratio (SAR) problems that can severely reduce infiltration rates. It is therefore recommended that any snowmelt containing deicing salts be diverted away from the underground infiltration chambers.

As shown on Table 7, the total phosphorus load after the Costco redevelopment is expected to increase by about 1.37 lb/yr. This increase is estimated to occur despite the project's treatment of stormwater originating offsite. Detailed information for this analysis is included in Appendix F.

**Table 7: Summary of Calculated Total Phosphorus Discharges at Hidden Meadow and Costco Sites (total phosphorus runoff discharges, lb/yr)**

	Hidden Meadow (15.5 ac developed area)	Costco (24.3 ac redeveloped area)
A. Site undeveloped (Hidden Meadow) or previously developed (Costco) (all seasons)*	1.57	12.32
B. Site developed (or redeveloped) (non-winter seasons) (not including off site area)	1.86	8.73
C. Site developed snowmelt (estimate)	0.80	5.53
D. Total site developed (or redeveloped) all seasons (B plus C) (not including off site area)	2.66	14.26
E. Site change with development (or redevelopment) (D minus A)	1.09	1.94
F. Off-site change due to treatment onsite	0.87 reduction	0.57 reduction
G. Net change (E minus F)	0.22	1.37

\* these calculations did not include assumed increased TP discharges associated with swales or biofilter use.

### **Conclusions**

It is highly unlikely that treated stormwater from a development project proposed at an undeveloped site (e.g. forest, meadow) in the New York City Watershed will be able to achieve no net increase in TP loading (mass discharges). Reductions in either (or probably both) concentration and runoff volume will be necessary to meet pre-development conditions. Unfortunately, few stormwater controls provide the very large reductions in TP concentrations necessary to consistently achieve a no net increase concentration goal of 150 µg/L. Additionally, if runoff volumes are not strictly controlled during new development, even further concentration reductions would be needed to meet the pre-development TP loads. Treatment of stormwater originating offsite will often be necessary to make up for the likely increases in phosphorous loading.

Besides reducing concentrations, most current stormwater control strategies also emphasize reducing runoff volumes. Many infiltration controls can provide volume reductions, but the amount that can be infiltrated is highly dependent on site conditions, and the size and design of the stormwater control. Therefore, the selection of suitable stormwater controls for a site is much more complex than just choosing from a treatment option menu and applying an assumed level of control. Combinations of controls that incorporate sedimentation, possibly sorption/ion exchange, along with infiltration would be an effective strategy for achieving low TP concentrations and reduced runoff volumes. Chemical control may also be effective at reducing TP concentrations, although data are limited on their application to stormwater.

In general, stormwater treatment technologies are not as consistent in performance as wastewater treatment processes, due to highly dynamic stormwater conditions (especially episodic high flows along with fluctuating stormwater concentrations and other attributes). This results in highly variable unit process performance for stormwater controls associated with contact times, settling periods, interactions with other constituents, extreme temperatures, etc., and results in periodic exceedances during unusual conditions.

Table 7 summarized the pre- and post-development total phosphorus discharges for typical residential and commercial developments in the New York City Watershed. This table shows the calculated total phosphorus mass discharges for pre-development and post-development conditions. Estimates for snowmelt total phosphorus discharges are also shown, based on simple calculations. These snowmelt discharges account for about one-third of the annual total phosphorus discharges.

Snowmelt can create problems in areas where the sodium in de-icing salts reacts with clay in soil causing significant reductions in infiltration capacity (sodium adsorption ratio). Snow handling at developed sites also makes discharge calculations uncertain as much snow is typically removed from the area and placed in adjacent undeveloped areas.

Both of these example developments incorporate a wide variety and extensive use of stormwater management practices. However, they are still expected to result in increased total phosphorus discharges compared to pre-developed conditions. These sites also include additional treatment of off-site stormwater that drains to site controls, providing additional total phosphorus reductions compared to pre-developed conditions. For Hidden Meadow, approximately one pound (1.09 pounds) of TP was estimated to be leaving the site each year post-development. With offsite stormwater treatment, this number was reduced to 0.22 pounds of TP leaving the site each year. For Costco, approximately two pounds (1.94 pounds) of TP were estimated to be leaving the site each year post-development. With offsite stormwater treatment, this number was reduced to 1.37 pounds of TP leaving the site each year. In each example, the no net increase goal for TP was not met. One method to further reduce the total phosphorus discharges would be to increase the treatment of off-site stormwater.

### ***Recommendations***

1) Total phosphorus loading regulations or guidance criteria should be updated to reflect up-to-date published performance information (*see* Appendices). Stormwater management is a rapidly changing field and new types of stormwater controls and data are periodically described in the literature and at technical conferences. In many locations, monitoring results from new promising stormwater controls demonstrate their ability to help meet local objectives. As the reliability of these new controls become acceptable, they need to be incorporated into guidance manuals.

2) Recent research indicates that some stormwater controls can do more harm than good. Appendix B demonstrates that effluent TP concentrations can increase with bioretention, grass filter, and grass swale stormwater controls compared to influent concentrations. This has been attributed to stormwater coming into contact with compost and other unstable organic materials, fertilized landscaped surfaces, and even soils that have high natural TP

concentrations (as may occur in grass filters and swales). These treatment devices may be desirable to encourage infiltration, but their TP release potential must be considered. Bioretention facilities can use media with lower TP release potential (such as sand/peat mixtures). Bioretention/biofilter underdrains, while needed to reduce surface ponding times in marginal soils, are not necessary at all locations. With no underdrains, the stormwater in contact with the media is mostly infiltrated, also reducing TP production potential of surface discharges. Fertilizer restrictions, especially in flow channels, can also reduce TP releases. Any increases in TP concentrations would need to be offset by increased infiltration of runoff volume, in addition to meeting the main objective of no net increase in TP discharges with development. Media filters, porous pavement, wet retention ponds, and wetland basins had lower TP effluent concentrations than other stormwater controls, with median TP concentrations of about 110 µg/L. However, the effluent from these controls still exceeded the 150 µg/L pre-development TP concentration during more than 25% of the monitored events.

3) No net increase in phosphorous is an appropriate goal for stormwater practices in areas having critical phosphorus problems in receiving waters. However, just meeting pre-existing TP discharges with development will not improve the receiving water condition, but will maintain existing problem levels. Acceptable pollutant analysis tools to evaluate pre- and post-development discharges should include continuous flow models, and not single-event drainage design models (a review of stormwater models is attached in Appendix D). Regulators should also invest in gathering suitable performance and calibration data to support any model selected for use. Basic information on stormwater quality and quantity should be obtained through monitoring. These data are available for many areas of the country and regional analyses allow preliminary model calibration. However, in areas where stormwater is suspected to be a major contributor to receiving water problems and extensive controls are likely needed, as in the Watershed, obtaining local data is a good investment to decrease uncertainty in stormwater management planning and expensive implementation.

More specifically, the following are general steps on how to develop the necessary modeling analyses:

- a. Collect and evaluate existing stormwater quality data. This should be from monitoring typical new developments, along with typical pre-development sites. The receiving water data may be useful, but regional characterization data is critical.
- b. Monitor typical stormwater control practices that are being used to meet TP targets with development. Update stormwater guidance documents based on available literature and other information to assist with this activity.
- c. Evaluate existing receiving water monitoring for use with lake/reservoir models (some of which is already being done in the Watershed).
- e. When sufficient data have been collected as part of 1) and 2) above (based on data quality objectives, as described by Burton and Pitt 2002), calibrate and verify a stormwater quality model that can be used to evaluate future projects. As an example, the USGS has been collecting stormwater quality and quantity data for the Wisconsin Department of Natural Resources for many years, to

support the use of WinSLAMM as the main tool to evaluate proposed developments, and retrofitting controls in municipal areas. This is conducted in lieu of each municipality conducting its own monitoring program. Compliance is demonstrated through the use of the verified model.

- f. Compliance/verification monitoring would be part of 3) to confirm the success of the strategy. Adjustments will likely be necessary as regional data are collected.

4) It is very difficult to match pre-development forest and meadow total phosphorus (TP) discharge after development. One way to address this problem is by using combinations of different stormwater treatment controls (in series, as in a “treatment train”) that utilize different pollutant removal pathways. For example, incorporating sedimentation with possibly sorption/ion exchange processes, along with infiltration might be an effective strategy for achieving low TP concentrations and reduced runoff volumes. The use of chemical controls may be effective for TP reductions, but performance data are limited.

5) Another way to address the challenging problem of meeting pre-development forest and meadow conditions for TP at a large development project is to reduce TP discharges from offsite sources. This can be accomplished by offsetting or compensating for increases in post-development onsite TP by treating stormwater at offsite properties (e.g. treating stormwater from adjacent offsite roadways).

6) Stormwater management in northern areas that use deicing chemicals needs to carefully consider the effects of elevated chlorides in shallow groundwater and the effects of increased sodium on clayey soils in infiltration facilities. It is not possible to treat snowmelt to reduce the chloride and sodium, so management practices that minimize their use (including the use of alternatives), careful movement of snow around a site, and diversion of snowmelt away from infiltration devices, should be considered.

## Appendices

The technical details pertaining to TP characteristics in stormwater and associated removal technologies appear in Appendices A through F of this report. Below is a summary of the information provided in each appendix.

- Appendix A: provides an analysis of TP data in the National Stormwater Quality Database. According to this analysis, location, land use, and season can all affect the expected total TP concentrations in stormwater. Data from the upper Midwest and Northeast U.S. were examined and three statistically significant land use groups were identified: 1) residential land uses (low density suburban to high density residential areas), 2) open space (such as parks, golf courses, and cemeteries) plus industrial land uses, and 3) institutional land uses (such as schools and government facilities) plus commercial land uses (central business districts, shopping centers and strip commercial). (There were too few observations from freeway locations in these regions for comparison).

Limited data indicates that snowmelt from developed urban areas can contribute relatively large TP loads to a receiving water. These discharges, and their control, also need to be considered when evaluating changes in TP loads associated with development.

- Appendix B: The International Stormwater BMP Database evaluates the performance of stormwater controls. This appendix summarizes the effectiveness of stormwater treatment on TP and includes: biological filtration, bioretention, dry detention basins, grass filter strips, grass swales, inlet inserts, media filters, oil/grit separators, physical separators, physical separators with volume control, porous pavement, sand filtration, treatment trains, wetland basins, wetland channels, and wet retention ponds.

- Appendix C: presents state regulations restricting the use of TP in fertilizers and laundry detergents. These regulations are an important part of TP control in developed areas, but need to be used in conjunction with other stormwater controls.

- Appendix D: presents information for a number of models that can evaluate TP sources, discharges, and controls in urban areas. Many of the most common models were developed to assist with drainage design, where large single storms were evaluated. Some users have adapted these methods to evaluate smaller precipitation events and their impacts on water quality. If only outfall flow conditions are desired, and data are available to verify the model, these models can be reasonably accurate. However, these modified models are often in error when quantifying pollutant sources and can lead to large errors when applied to smaller precipitation events and to water quality analyses. Models used without verification may be suitable for preliminary analyses, with the understanding that greater uncertainty will accompany the results.

- Appendix E: Hidden Meadow Development Stormwater Analysis Summary. As noted earlier, the Hidden Meadow development is on a forested site. It is about 35 acres in size, with about 10 acres developed in multi-family residences, parks, and roadways, and 5 acres of undeveloped area that drains onto the developed area. The stormwater quality model,

WinSLAMM (version 10.3), was used to calculate the expected post-development stormwater quality (focusing on total phosphorus) for this typical residential development.

The total phosphorus load after development is expected to increase by about 0.22 pounds per year, even with the extensive stormwater controls at the site and offsite stormwater treatment. Detailed information for this analysis is included in this appendix.

- Appendix F: Costco Stormwater Analysis Summary. The Costco site is a redeveloped area that was originally occupied by a plant nursery/lawn mower service center, two residential properties, a former motel and a fence company. The re-developed area is comprised of large parking areas and a large Costco building, along with several outbuildings. The total area is about 24 acres. The pre- and post- redeveloped site areas were evaluated using the stormwater quality model, WinSLAMM (version 10.3), to calculate stormwater total phosphorus discharges for this typical redevelopment commercial project.

The total phosphorus load after re-development is expected to increase by about 1.37 pounds per year, even with the extensive stormwater controls at the site and offsite stormwater treatment. Detailed information for this analysis is included in this appendix.