Technical Background For Retrofitting Practices
EOH MS4 Heightened Criteria

The Municipal Separate Storm Sewer System (MS4) General Permit defines a "retrofit" as a means of modifying or adding to existing stormwater infrastructure for the purpose of reducing pollutant loadings. To set a reduction goal for phosphorus removal in the East of Hudson (EOH) watershed, this document was prepared to address a few basic questions in this process:

- What is the urban load estimate from each MS4 in the EOH watershed?
- What is a reasonable reduction that could be expected from this load?
- What kind of practices are acceptable as retrofit options?
- How will DEC measure progress?

To this end a brief analysis was performed to define short and long term retrofit options as follows:

- The attainable reduction level was determined to range from 0.136 to 0.227 kg of phosphorus per acre in qualifying watershed areas.
- The acceptable methods for quantifying short term reduction level were examined. These methods must be further enhanced for long term implementation.
- Three computational methods were utilized to determine load reduction, each providing utility for certain retrofit options, including:
    - Non-structural practices and management options (WTM)
    - Structural practices & specific design/reduction evaluation (WinSLAMM)
    - Watershed wide comparative analysis for long term goals (AVGWLF)
- A menu of effective stormwater management practices was developed to include:
    - Effective treatment mechanisms for site specific retrofits
    - Prevention of source area contribution and overall watershed management
- An implementation plan including short and long term goals was defined as:

    - Specific selected practices applied throughout priority areas for short-term implementation (e.g. road ditch retrofit and rooftop disconnection) with a predetermined budget
    - Wider range of practices selected based on site specific analysis and cost effectiveness analysis for long-term implementation (future funding)
- Short term goals were defined based on:
    - Load estimates due to high density development from each MS4
    - Reductions based on MS4 contribution in priority watersheds
- Long term goals to be defined based on further analysis by MS4s and/or a regional stormwater entity (RSE)
- Water quality measurement by monitoring stormwater discharges at key points in the watershed will be essential for verification of such analysis and implementation.

Modeling Discussions

An effective retrofit program involves the following:

- identification of problem areas
- field verification of potential retrofit sites
- estimation of pollutant loads
- prioritization of contributing areas
- prioritization of feasible retrofit options based on potential for load reduction
- design and installation of retrofits
- periodic monitoring at critical points.

The Urban Stormwater Retrofit Practices Manual, developed by the Center for Watershed Protection (August 2007), lays out a step-by-step process for urban watershed restoration by stormwater retrofit. The following approach is adapted for NYS conditions and specifically for the NYC EOH watershed.

Load Reduction

To define a specific load reduction goal a series of scenarios were examined and a range of potential phosphorus load and achievable reduction methods were estimated by

alternative calculation methods. A comparative analysis was used to derive a load reduction for a typical residential site.

Three watershed models, WTM (Watershed Treatment Model), WinSLAMM (Source Loading And Management Model)(Pitt, 2002), and AVGWLF (ArcView Generalized Watershed Loading Function)(Evans, 2002) were selected for this analysis. Typically the results of the load calculations were different due to different methodologies, including:

- WTM provides a simple method hydrology computation based on the average annual precipitation, while WinSLAMM and AVGWLF utilize a continuous hydrology simulation.
- WTM hydrology calculation is driven by the imperviousness of the contributing area, while WinSLAMM and AVGWLF incorporate physical characteristics of the contributing area such as soil type and infiltration capacity.
- WTM uses annual loading rates for a wide range of practices, AVGWLF utilizes engineering functions for a lumped calculation of watershed-wide loads, while WinSLAMM uses empirical data for simulation of the physical characteristics of the watershed and design features of urban stormwater practices.
- WTM provides a simple spreadsheet screening tool; WinSLAMM allows a detailed analysis BMP retrofit option while AVGWLF, utilizing the same model engine as the modeling tool for NYC watershed TMDL, provides a base for comparative analysis.

Scenarios

To estimate a typical phosphorus loading, the modeling was performed utilizing two approaches: site specific and watershed wide analysis.

For site specific estimates a 100 acre high density residential area was modeled utilizing WTM and WinSLAMM. This scenario accounted for both impervious area phosphorus build up, wash-off and pervious area contribution such as turf grass landscape areas subject to fertilizer application. WTM provided variable outputs depending on selected BMPs. To estimate load reduction an open channel/enhanced grass swale design was simulated.

In watershed wide analysis two major load sources, septic and urban runoff load, were evaluated utilizing AVGWLF. Urban runoff was simulated based on high and low intensity development. Load reductions were applied by assuming a percentage reduction to surface runoff load estimates.

In modeling of retrofit options the enhanced road ditch was selected based on a few key factors. Open channel / enhanced grass swales can often be installed in a variety of conditions, including linear development and residential areas. They require less footprint as they replace existing conveyance systems and are more adaptable within the constraints of existing infrastructure, which sets an achievable goal. Therefore, their adaptability outweighs the removal efficiency of recommended practice. Load reduction may increase incrementally as more effective practices are utilized.

Model Results

Results of the site specific model runs for different rain years in locations within the EOH watershed (except one rain gage located outside of the watershed) show that a 14 kilogram phosphorus reduction from a 100 acre developed site is a reasonable expectation. This level of reduction may be achieved in areas with an average of 35 percent impervious surface, and can be interpreted as about 30% load reduction. It must be noted that mass reduction may increase depending on watershed characteristics such as rain pattern and clay content of the soil. This can result in higher existing load, while BMP effectiveness remains the same. This result is also based on the assumption that the total water quality volume is captured and treated. Such a scenario may not always be achievable in retrofit conditions. However, where use of more effective practices is feasible or the imperviousness of the contributing area increases, 30% reduction can still be achievable.

Table 1. Comparison of phosphorus reduction by WTM and WinSLAMM results

Model	Scenario, Rain year	Scenario Variables	Rain (in)	Load (kg) no ctrl	Load (kg) with ctrl	Reduction (kg)	Reduction %
WTM	1st	AT*: 13 ac roads	45	43.5	38.6	4.9	11%
WTM	2nd	AT: 22 ac road, sidewalk, driveway	45	43.5	34.9	8.6	20%
WTM	3rd	AT: 37ac Imp.	45	43.5	29.5	14.0	32%
WinSLAMM	Carmel, 93	clay soil	35	137.4	86.2	51.2	37%
WinSLAMM	Carmel,93	sandy soil	35	28.6	1.8	26.8	94%
WinSLAMM	Carmel, 94	clay soil	14	66.7	53.5	13.2	20%
WinSLAMM	Carmel, 94	sandy soil	14	27.2	1.4	25.8	95%
WinSLAMM	Poughkeepsie, 93	clay soil	38	105.2	55.8	49.4	47%
WinSLAMM	Poughkeepsie, 93	sandy soil	38	27.2	1.4	25.9	95%
WinSLAMM	Poughkeepsie, 99	clay soil	21	41.3	15.0	26.3	64%
WinSLAMM	Poughkeepsie, 99	sandy soil	21	14.5	0.5	14.0	97%
		Min.	14	14.5	0.5	14.0	11%
		Max.	45	137.4	86.2	51.2	97%
		Avg.	32	52.6	29.0	23.6	56%
		Median	35	43.5	29.5	25.9	

*AT: Area Treated

In addition to estimated reduction by grass swale or open channel design, potential reduction from rooftop disconnection is evaluated. The Center for Watershed Protection estimates that most communities own or control about ten percent of land in their watersheds, such as parks, schools, roads and municipal buildings. Public lands not only provide a target for stormwater retrofits, they also can be used as infiltration areas for other types of development. The WTM is used for rooftop disconnection. The model run for a 100 acre high density development site roughly estimates about 50% load reduction. This reduction is due to hydrologic source control of small storms.

The AVGWLF model provides output results of loads per watershed and a breakdown for each municipality's contribution. The model output included nutrient and sediment loads from high intensity development (HID) and low density development (LID). The output

result of this modeling is primarily used to prioritize the contribution of individual MS4s in each sub-watershed. The results of the AVGWLF model run is presented in Table 2. It must be noted that the AVGWLF default statewide data (such as MRLC data for land use/land cover, STATSGO for hydrologic soil group, etc.) is utilized for this analysis. Load estimates may be reevaluated if more detiled local data is available. Simulation of more specific urban land uses is also possible if the enhanced version of AVGWLF, with RUNQUAL module, is utilized. As more advanced modeling tools become available, more comprehensive computation for design, siting, optimization, and cost-effectiveness comparison may provide a more refined analysis.

The estimated total load indicates potential phosphorus reduction of 0.29 kg/ha from high density developed area if retrofit practices with 30%-50% efficiency are employed. It must be noted that these values indicate the load through overland flow or conveyance system (does not include subsurface flow/groundwater contribution). This model also provides estimated values from other sources of phosphorus such as septic systems (based on non-sewered populations), stream bank erosion and other land use and land covers, which are not included in this report.

Table 2. AVGWLF model results for the EOH watershed

Watershed	Area (ha)	Urban (ha)	LID (kg P)	HID (kg P)	LID (ha)	HID (ha)
Croton	15,025	2,437	163	521	1,754	683
Amawalk	5,088	1,160	66	198	848	312
Muscoot	19,594	4,124	291	939	2,953	1,171
Boyds Corner	5,794	121	9	35	81	40
West Branch	5,154	345	28	65	261	84
Croton Falls	4,139	616	7	6	447	169
Lake Gilead	170	50	3	7	39	11
Lake Glenida	168	9	1	1	8	1
Middle Branch	5,421	626	40	155	425	201
East Branch	19,452	947	70	164	735	212
Titicus	6,303	432	44	31	393	39
Cross River	7,767	628	46	126	471	157
Kensico	3,430	465	32	110	342	123
Bog Brook	957	40	2	10	24	16
Diverting	1,944	545	29	113	367	178
Total	**100,407**	**12,545**	**831**	**2,480**	**9,148**	**3,397**

The breakdown of load in high density development (HID) indicates a total of about 2,480 kg per year, which may be controlled in each municipality according to their contribution. Level of reduction can be assigned based on the number of years that a retrofit plan is implemented. Similar allocation may also be applied based on road mileage owned by each MS4.

Table 3. AVGWLF model results by each municipality's contribution and the significance of the receiving reservoir and estimated 30% reduction.

Watershed	Municipality	% Load by MS4	HID Load by	Reduction (kg)
Croton	Bedford	2	46	13.8
	Cortlandt	2	49	14.7
	Mount Kisco	5	115	34.5
	New Castle	5	131	39.3
	North Castle	0	0	0
	Somers	0	5	1.5
	Yorktown	5	134	40.2
Amawalk	Carmel	8	190	57
	Putnam Valley	0	0	0
	Somers	1	30	9
Muscoot	Bedford	6	143	42.9
	Carmel	2	48	14.4
	Lewisboro	3	72	21.6
	North Salem	4	106	31.8
	Pound Ridge	1	23	6.9
	Somers	8	207	62.1
	Southeast	1	34	10.2
	Yorktown	6	153	45.9
Boyds Corner	East Fishkill	0	4	1.2
	Kent	2	38	11.4
	Putnam Valley	0	5	1.5
West Branch	Carmel	1	30	9
	East Fishkill	0	2	0.6
	Kent	2	36	10.8
Croton Falls	Carmel	4	106	31.8
	Kent	1	25	7.5
	Somers	0	6	1.8
	Southeast	0	2	0.6
Lake Gilead	Carmel	0	1	0.3
Lake Glenida	Carmel	0	9	2.7
Middle Branch	Beekman	0	1	0.3
	Carmel	0	5	1.5
	East Fishkill	1	12	3.6
	Kent	4	88	26.4
	Patterson	1	12	3.6
	Pawling	0	2	0.6
	Southeast	2	45	13.5
East Branch	Beekman	0	0	0
	Kent	0	1	0.3
	North Salem	0	6	1.8

	Patterson	4	98	29.4
	Pawling	2	48	14.4
	Southeast	2	39	11.7
Titicus	Lewisboro	0	1	0.3
	North Salem	1	16	4.8
Cross River	Bedford	0	2	0.6
	Lewisboro	5	114	34.2
	North Salem	0	0	0
	Pound Ridge	1	22	6.6
Kensico	Harrison	0	8	2.4
	Mount Pleasant	1	15	4.5
	New Castle	0	5	1.5
	North Castle	2	51	15.3
	White Plains	0	0	0
Bog Brook	Patterson	0	1	0.3
	Southeast	0	3	0.9
Diverting	Brewster	2	37	11.1
	Patterson	0	0	0
	Southeast	4	98	29.4
Total		100	2480	744

On an average basis the reduction may result in 0.136 to 0.227 kg per acre/year. This phosphorus reduction falls within the range acknowledged by available literature values. Table 4 displays the export coefficients reported in the Nonpoint Source Watershed Planning Handbook, March 08. According to values presented in this report, setting the goal for removal of 0.136 to 0.227 kg of phosphorus from a typical residential area seems reasonable.

Table 4. NPS handbook export coefficients

NPS watershed planning handbook
Ag. C. from Reckhow et al. (1980), urban C. from Athayde et al. (1983)

Land Use	P Export Coefficient (kg/ha/yr)
Residential	1.2
Business	3
Industrial	3.8

While higher load reduction in other types of development seems achievable, more impervious land uses can preclude opportunities for capture and treatment of the total water quality volume. The Urban Stormwater Retrofit Practices (August 2007) reports a phosphorus export value of 0.91 kg/acre/year in urban development. A simple estimate indicates that, on an average basis, capture and treatment of 50% of the load by a practice capable of 30% removal rate can result in 0.136 kg/acre reduction.

A menu of best management practices may include retrofit options that specifically target phosphorus removal at varying levels of implementation. Some tasks are focused on phosphorus treatment and some utilize mechanisms that minimize mobilization of mineral phosphorus by erosion. These practices range from effective treatment mechanisms for site specific retrofits to those which provide prevention of source area contribution and overall watershed management strategies. A wide range of BMPs provides more options for an adaptable program throughout the watershed.

This list includes both quality controls (from simple source control practices to advanced treatment systems) to hydrology and hydraulic controls (energy dissipation to flood control mechanisms). Most achievable tasks may be implemented immediately, some periodically on certain intervals or as needed, and some may be planned for long-term implementation. This list includes storage/detention systems, on-site/conveyance retrofits, downstream controls, and management measures. More detailed retrofit options and available tools (identified as WTM=1, WinSLAMM=2, AVGWLF=3) for evaluation of candidate management practices are listed in Table below. Additionally, other models that may provide more powerful tools, such EPA's System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN) maybe used for this purpose:

Table 5. List of retrofit options and available modeling tools.

Retrofit Category	**Management Practice**	**Modeling Tool**
Conveyance System Upgrade	Conversion to Enhance Dry Swale	1
	Conversion to Grass Swale	1, 2
	incorporation of deep sump catch basins	2
Retrofit of existing storm sewer systems by Standard stormwater treatment systems	Ponds, Wetlands, filtering, infiltration, and open channels	1, 2
	Conversion of dry detention ponds to treatment systems	1, 2
	Conversion of dirt parking lots to pervious pavement, grassed or stone cover	2
	Proprietary practices	2
Retrofit of existing storm	Roof top disconnection	1, 2

sewer systems by Better Site Design (Green Infrastructure)	Soil de-compaction Riparian buffers Impervious area reduction	1
	Reforestation and tree planting	2, 3
	Stream daylight Rain Gardens Cisterns Green Roofs Blue Roofs	SUSTAIN
Stabilization of dirt roads	gravel, stone, water bar, check dam, diversion	1
Retrofit by converting abandoned buildings	stormwater treatment systems	1,2
	to open space or infiltration areas	1,2
Hydrology/Hydraulic controls	Control of the downstream effects of runoff from existing paved surfaces resulting in flooding and erosion in receiving waters	H&H, WQ models
	Control of stream erosion by plunge pool, velocity dissipaters, and flow control devices for discharges	H&H, WQ models
Upgrade of an existing conveyance system	Techniques for water quality improvement (pretreatment, catchbasin, etc.) Techniques for quantity control within the drainage structure Improvement of storage capacity and detention Provision for illicit discharge elimination of	H&H, WQ models
Adopting Regulation	maximum exposed soil, grass establishment for existing eroded areas, prior to occupancy, etc.	
	land development control, percentage of pervious to impervious area, local codes on roads/sidewalkparking area sozing, protection of sensitive areas, conveyance system upgrade, standard treatment for retrofit projects	

Reduction Values:

To evaluate the load reduction value of retrofit projects, effectiveness of stormwater management practices need to be identified. Empirical values of removal efficiency for several treatment systems have been studies and documented by different sources. The range of reported removal rate of monitored practices, according to the most recent updates to the National Pollutant Removal Performance Database (Winer, 2000) is listed in Table 7. University of Minnesota report on cost effectiveness of practices provides a compilation of the removal efficiency of stormwater treatment systems that appear in Table 7. Many other stormwater practices, such as hydrologic source control and low impact development, need further evaluation for their phosphorus removal effectiveness.

Table 6. Range of reported removal rate of phosphorus by different treatment practices (percent)

BMP	Phosphorus form	Low	Median	High
Dry Detention Pond	Particulate	15	20	25
	Soluble	-10	-5	10
Wet Pond	Particulate	40	50	75
	Soluble	40	65	75
Filters	Particulate	40	60	65
	Soluble	-10	5	65
Infiltration	Particulate	50	65	95
	Soluble	55	85	95
Wetlands	Particulate	15	50	75
	Soluble	5	25	55
Swales	Particulate	-15	25	45
	Soluble	-95	-40	25

Table 7. Expected phosphorus removal (Weiss, 2005)

TYPE	Typical Phosphorus Removal (%)[1]	Median Removal Efficiency (%)			No. of Observations (respectively)
		Total	Dissolved	Ortho-	
Dry Detention Basin	15 - 45				
Wet/Retention Basins	30 - 65	46[3]	34[3]		44, 20
Constructed Wetlands	15 - 45	46[2]	23[2]	28[2]	37, 12, 7
Infiltration Basins	50 - 80	65[3]			5
Infiltration Trenches/Dry Wells	15 - 45				
Porous Pavements	30 - 65				
Grassed Swales	15 - 45				
Vegetated Filter Strips	50 - 80	15[3]	11[3]		18, 8
Surface Sand Filters	50 - 80	45[3]	-31[3]		15, 2
Other Media Filters	< 30				

Proposed short term goals

It is recommended to apply a few selected practices, with known effectiveness and cost throughout the priority areas in the watershed for immediate implementation during the span of the GP-0-08-002. Two recommended practices, conversion of road ditches to enhanced open channel/grass swale and disconnection of rooftops, are highly compatible with relatively constant associated cost. Siting of these practices are manageable in a short term plan and can be easily installed in publicly owned property and roadway right-of-way.

Proposed long term goals

Watershed screening:

Retrofit project selection and siting benefit from a desktop GIS screening and evaluation for identification of candidate sites. This evaluation provides a good tool as first cut screening for siting projects and must be followed by field verification and site survey to examine and select most effective treatment systems for the identified problems.

Evaluation of proposed retrofit plans involves identification of associated costs and assessment of cost-effectiveness of alternative scenarios. The next step, once the

watershed loading contribution is prioritized, is to select most valuable project by evaluation of the potential load reduction for estimated cost for candidate projects.

Watershed model:

For long term implementation of a successful retrofit plan, it is necessary to provide appropriate tools to the regulated communities to perform the above analysis in a comprehensive fashion in their day-to-day operations. Both pervious and impervious areas are found to contribute to phosphorus load during small storm as well as erosion (phosphorus in mineral form) during flooding events. Enabling municipalities to have an understanding of the hydrology, hydraulics and pollutant loading processes in their watershed is essential.

An appropriate watershed model can be set up by the state and utilized by the municipalities as a decision-making tool to determine potential discharge reductions, their retrofit options, and budget their resources. A few benefits of such system include:

Identify source, significance of the reduction, estimate of associated cost to make a determination on a long term cost effective plan that sets the priority for the entire watershed.

Comparative analysis on the feasibility and cost of the retrofit options

Identify flood prone areas and target mineral source of phosphorus from channel bank erosion.

Examine the effects of the runoff from existing urbanized areas on downstream water channel morphology and the potential in stream erosion.

Use the watershed model to examine the effects of the new developments on downstream waterbody hydraulic response to the hydrologic modification to prevent flooding and downstream erosion.

Model the watershed to evaluate the existing and proposed flow devices for their collective hydrologic effect and minimize the impact of individual detention systems.

Model the watershed for banking and trading of credits that individual projects may present.

Model the watershed for tracking the progress of the MS4 program implementation.

Conclusion:

The retrofit program defined under the Municipal Separate Storm Sewer System (MS4) requires modification to the existing stormwater infrastructure for the purpose of reducing pollutant loadings. To set a reduction goal for phosphorus removal in the East of Hudson (EOH) watershed, this document provides the urban load estimate from each MS4 in the EOH watershed, a reasonable reduction from this load, acceptable retrofit practices, and methods of measuring progress to that end. This analysis defines short and long term retrofit options with an attainable reduction level is 0.136 to 0.227 kg of phosphorus per acre in qualifying watershed areas. Recommendation are made for short term retrofit action in readily available infrastructure and long term planning and design of more advanced treatment system for more effective phosphorus reduction.

References:

Caraco, D. Watershed Treatment Model (WTM) User's Guide – Version 3.1 Center for Watershed Protection (CWP), 2002

Center for Watershed Protection Manual 3, Stormwater Retrofit Practices. Small Urban Watershed Restoration Manual Series. August 2007

Evans, B.M., D.W. Lehning, K.J. Corradini, G.W. Petersen, E. Nizeyimana, J.M. Hamlett, P.D. Robillard, and R.L. Day. A Comprehensive GIS-Based Modeling Approach for Predicting Nutrient Loads in Watersheds. J. Spatial Hydrology. 2(2). Available at http://www.spatialhydrology.com/ 2002

Handbook for Developing Watershed Plans to Restore and Protect Our Waters, EPA 841-B-08-002, March 2008

Phase II Phosphorus Total Maximum Daily Loads For Reservoirs in the New York City Watershed, June 2000

Pitt, R. and J. Voorhees, http://www.winslamm. Com, 2002
Recommendations to the New York State Department of Environmental Conservation for the Development of its Phase II TMDL Implementation Plan, April 2004

Tetra Tech, Inc. and USEPA Office of Research and Development, Optimizing BMP Placement at Watershed-Scale Using SUSTAIN, Paper presented at World Environmental and Water Resources Congress, May 2008, Honolulu, HI.

Winer, R. National Pollutant Removal Database for Stormwater Treatment Practices: 2nd Edition. Center for Watershed Protection. Ellicott City, 2000