Enhanced criteria for phosphorus removal from stormwater discharges In the New York City watershed

Amélioration du critère de traitement du phosphore dans les rejets d'eaux pluviales dans le bassin versant de la ville de New York

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RÉSUMÉ

Les risques liés au phosphore dans les eaux pluviales et qui affectent la qualité de l'eau potable à New York nécessitent un traitement spécifique anti-polluant des ruissellements. Un ensemble de critères a été développé en vue de l'élimination effective du phosphore des ruissellements résultant d'activités de développement. Les critères améliorés sont basés sur les résultats des dernières recherches sur site, de la modélisation de la réponse hydrologique aux systèmes de traitement et de la simulation des mécanismes d'élimination du phosphore. Les critères proposés qui font appel à trois contrôles primaires – minimisation des ruissellements, optimisation de la collecte de volume de traitement et minimisation des concentrations dans les effluents – optimisent les performances des systèmes au-delà des normes de l'état de New York.

ABSTRACT

The threat of phosphorus in stormwater impacting the New York City drinking water supply calls for a pollutant specific treatment of runoff. A set of criteria is developed to achieve effective phosphorus removal from stormwater discharges resulting from development activities. The enhanced criteria are based on the results of the latest field research, modelling the hydrologic response of the treatment systems and simulation of phosphorus removal mechanisms. The proposed criteria, which utilize three primary controls; minimizing runoff, maximizing the capture of treatment volume and the minimizing effluent concentrations; enhance the performance of systems above existing state standard.

KEYWORDS

Design Criteria, Phosphorus Removal, Stormwater, Treatment

INTRODUCTION

In January 2003, the New York State Environmental Conservation Department issued the Phase II Stormwater Permit, which requires capture and treatment of stormwater discharges from construction activities disturbing more than one acre of land. The existing State standards require capture and treatment of stormwater runoff from the 90th percentile 24-hour precipitation event. The numeric standards require a minimum treatment of 40% phosphorus and 80% total suspended solids removal by the use of acceptable stormwater treatment systems for which empirical removal rates are verified (NYSDEC, 2003). Additional measurements are required for stormwater discharges to impaired waterbodies, however, such requirements are not pollutant specific.

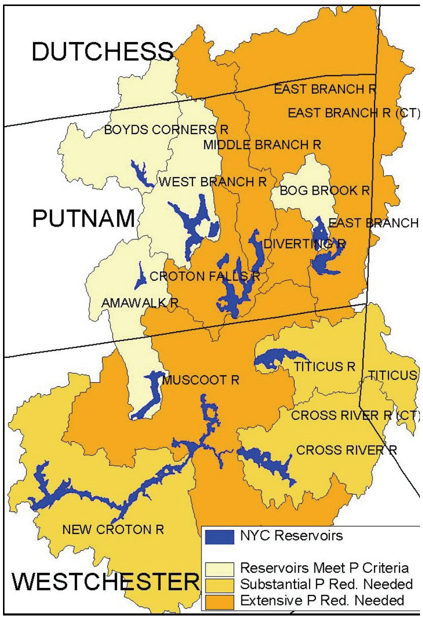

Figure 1. NYC water supply reservoirs in the East of Hudson watersheds

An excess amount of nutrient is harmful to aquatic environment. Over-fertilization accelerates plant growth and cause eutrophication of receiving water. The rapid growth of phytoplankton prevents photosynthesis by shading submerged aquatic vegetationNutrient enriched algal blooms can impair the suitability of water for municipal supplies, recreation, fishing, and wildlife. Direct impacts to reservoirs include undesirable taste and odor.

The Croton Watershed covers an area of 374 mi^2 and supplies approximately 10% of the total water demand of New York City. Urbanization of the Croton Watershed poses a risk of phosphorus load to the reservoir systems. (NYC DEP, 2003). A need for more restrictive requirements for stormwater treatment was identified in the early stages of permit implementation. A team of experts was formed to develop a technically defensible set of criteria to enhance the current state standards by defining the acceptable methodology, magnitude of treatment, effective technologies, as well as the feasibility of proposed approaches, which are presented in this paper.

The geo-chemical properties of phosphorus are utilized to define the mechanisms and pathways by which treatment can be maximized. Phosphorus is found in earth's crust, in the form of phosphate in minerals and as a constituent of plants and animals as ATP (adenosine triphosphate). ATP is needed for a key function of all life forms for energy storage and transfer for growth and reproduction. Under natural conditions it is present in both particulate and dissolved forms as organic phosphorus in humus, as insoluble in mineral phosphorus, and bioavailable phosphorus in soil solution. Combined with other ions, phosphorus converts to insoluble compounds and precipitates out of solution. In an aquatic environment phosphorus does not volatilize. It incorporates into biological solids, precipitates, and a significant portion retained in the system is recycled in particulate form (Tchobanoglous, 2003). Phosphorus treatment is a function of partitioning. In particulate form it depends on

the particle size distribution and densities, primarily by sedimentation and filtration. In dissolved form removal is a function of concentration and speciation, primarily by surface complexation reactions resulting in adsorption or precipitation. The latest studies of urban runoff indicate that phosphorus concentration is substantially higher where size of the particulate maters is less than 10 μm (Heaney, 2005).
Behaviour of phosphorus in natural systems is a key factor in selecting design elements to achieve effective treatment performance. Design factors that influence phosphorous removal processes, such as settling velocity as a function of particle size distribution of the particulate phosphorus, biological uptake of the dissolved phosphorous, and media contact time for adsorption or sorption of dissolved phosphorous, are used as the basis for recommending effective unit processes.

METHODOLOGY

The enhanced criteria for phosphorus removal are multi-faceted. They include criteria for sizing of storage and flow through systems, performance specifications, groundwater recharge, maintenance, and effective source control by practice selection and siting. The principle approach in defining the enhanced criteria is based on achieving effective SMP performance. A three part definition of effective SMP performance is used: 1) how much stormwater runoff is prevented, 2) how much of the runoff is captured by the SMP or by-passes the treatment system, and 3) what effluent quality can be expected to be achieved.

Source Control

The first element in preventing impairment of receiving waters from phosphorus is to reduce the actual volume of stormwater runoff that is generated, and subsequently reduce the total loads of phosphorous transported through runoff. Effective hydrologic source control can be achieved in a number of ways including reducing imperviousness, achieving hydraulic disconnection of impervious areas, and by maximizing evapotranspiration and infiltration. Source control can be achieved through micro scale hydrologic analysis and routing of the flows. The recommended standard hydrologic calculations, unlike the existing sizing method that relies on percentage of impervious area, includes both impervious and pervious areas in establishing water quality sizing of SMPs. This sizing approach encourages runoff reduction and utilizing the infiltration and evaporation capacity of soil.

Effective Capture

At the most basic level, performance of SMPs is realized through effective hydraulic function of SMP systems to achieve sufficient residence times and minimize bypass. To establish new criteria, two models were utilized to simulate the hydrologic and hydraulic function as well as the water quality performance of the treatment systems. Long-term continuous simulations were used for both hydraulic and water quality performance evaluations. Event-based simulations were utilized to identify the appropriateness of sizing based on design storms. The U.S. EPA Storm Water Management Model (SWMM) Version 4.4h was used to develop the continuous hydrologic, hydraulic, and water quality analysis. HydroCAD®, a computer aided stormwater design package, was used for evaluating the sizing performance. Two basic types of system configurations were evaluated in this study: a volume based to simulate online storage systems such as ponds and wetlands and a flow rate based to simulate offline flow through systems such as filtering and infiltration practices.

Storage systems

A continuous simulation model was used to evaluate the Wet Extended Detention Pond and Wet Pond designs in terms of estimated removal of a range of sediment particle sizes due to settling of particulate –bound phosphorus. Rainfall used for the simulation was taken from a 10-year (1985-1994) historic rainfall record for Carmel, New York. Percent capture is reported directly from the model as the fraction of total runoff volume that is discharged from the pond through the extended detention outlet. The settling of solids is modelled directly by standard particle settling theory and plug flow reaction kinetics using Stokes Law. The variables that were evaluated to determine the most effective design configuration included the size (acre-ft) of the Water Quality Volume (WQv), fraction of the WQv in permanent pool (PP_v), and draw-down time (hours) controlled by the size of the low flow orifice.

The estimated long-term water quality treatment performance of storage systems was calculated for three alternative design criteria using the existing design approach but altering the water quality volume of the facility. The three alternative water quality volumes evaluated were: 1) the current DEC standards (90%) event; 2) the 1-yr 24-hr storm event and 3) the 2-yr 24 hr storm event. The effects of varying design parameters on performance were examined by about 120 iterations. Figures 2 and 3 display the results of the continuous simulation model of particulate phosphorus capture for in the wet ponds for various particle size distributions and in the extended detention ponds with 50% pemanent pool and 24 hour Detention.

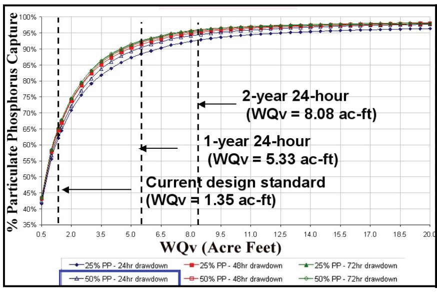

Figure 2. Particulate Phosphorus in the Wet Extended Detention Ponds

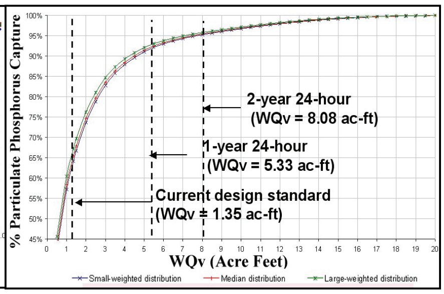

Figure 3. Particulate Phosphorus in the Wet Ponds

This analysis and the resulting new design criteria are intended to provide points of convergence for the existing requirements applied in phosphorus-limited watersheds, while maintaining consistency with the state stormwater standards. Therefore, additional analysis was performed to address the current requirements of the New York City Department of Environmental Protection, which calls for 24-hr detention of 2-yr storm. A series of analyses examined removal rates by either a plug flow or the Center-of-Mass 24-hr detention for seven WQv sizing scenarios with varied imperviousness. The results of hydrologic simulations, displayed in Figure 4 exhibited similar results.

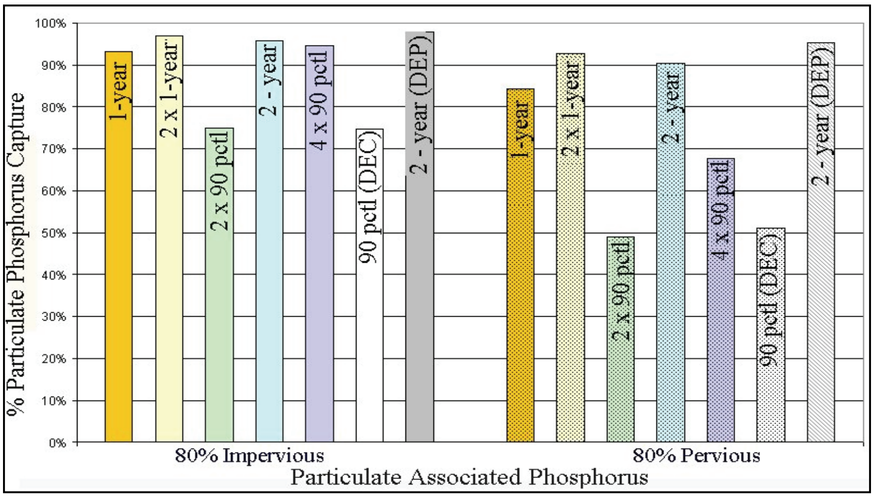

Figure 4. Alternative WQV Sizing for ED Ponds for Phosphorus (PSD < 10) µm

The results for both Wet Extended Detention and Wet Ponds indicate the significance of maximizing captured runoff and residence times resulting in improved removal of small particles (i.e., <10um). Based on the analysis conducted, the recommended sizing criteria for storage systems is that the water quality volume of both wet pond and extended detention ponds be set to the 1-yr 24-hr storm runoff volume using standard hydrologic design calculations (i.e. TR-20 and TR-55). This level of control achieves approximately 85% capture of particulate-associated phosphorus under varied watershed conditions.

Flow Through Systems

For the design of flow-through systems, the hydraulic performance is approximated by modelling of a basin sized to the calculated treatment volume with an orifice sized to match the stage-discharge relationship of the facility. Modelling of infiltration and filtration systems is highly contingent upon the coefficient of permeability, the underlying soil porosity, and the hydraulic conductivity of filter media. Design of both of the above systems is also highly dependent on the treatment surface area, which limits the sizing for an effective removal return. The filtering system was modelled as the total runoff volume that is not bypassed. The key design factor is established by setting a minimum of treatment surface area as a percentage of WQv. The requirement for enhanced phosphorus removal for sand filters is set to a volumetric capture of r85% of storm events. This is accomplished by sizing the sand filter for 65% of the WQv for the1-year 24-hour storm.

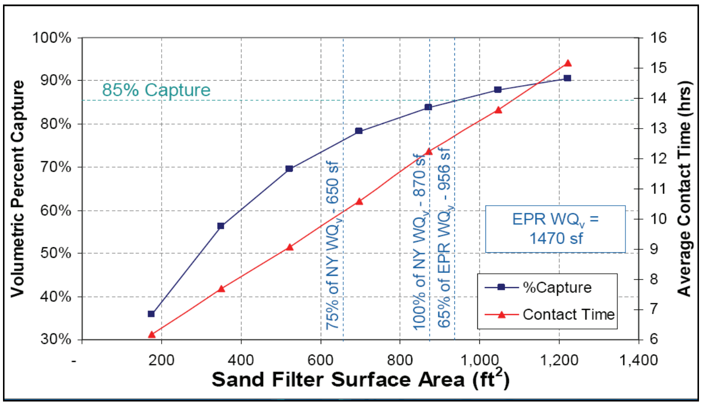

Figure 5. Volumetric Capture Vs. Filter Surface Area

Recommendation for infiltration systems remains as capture and recharge of 1-yr 24-hr storm events. The examination of the open channel design indicate that swales without integrated filtration should not be recommended as an alternative flow-through system due to the short residence time of the flow and inadequate treatment.

Effluent Quality

Effluent quality goals for particulate and dissolved phosphorus are based on analysis of available empirical influent and effluent water quality data for a variety of treatment systems and operational conditions (e.g. catchment characteristics, climate). Based on the analytical work that examined effluent concentrations in acceptable stormwater treatment, the requirement is set for flows that are treated by the system (i.e., flows that are not effectively bypassed), median effluent concentration of particulate phosphorus at or below 0.1 mg/L and for dissolved phosphorus at or below 0.06 mg/l (Heaney, 2005).

The vehicle to apply this set of criteria consists of various regulatory programs. In addition to the state-wide construction permit requirements, other key players such as City regulators, local municipalities, and operators of municipal separate storm sewer systems will have an opportunity to incorporate these heightened standards in their rules and regulations as well as potential watershed improvement projects and the retrofit of existing stormwater infrastructures.

CONCLUSION

The research conducted to support the technical basis for the enhanced criteria recommends a physically based design methodology, greater capture of pollutants by increasing treatment volume and minimizing bypass, as well as numeric limits for effluent concentration. The heightened criteria for stormwater treatment in the NYC watersheds far exceeds the tools used in current stormwater technical standards and provide a significant advantage in merging multiple regulatory design standards.

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