WET DETENTION FACILITY POLLUTANT REMOVAL MODELING

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ABSTRACT

Wet detention systems are a common type of storm water treatment facility in Florida that are effective in providing improved water quality. Historically, facility storm water treatment volumes for wet detention facilities have been determined using simple technology based standards (e.g., detention of one inch of runoff), which are readily understood by the practicing engineer and enforced by the permit reviewer. These traditional design standards, however, do not allow the designer to predict the resulting pollutant load reduction associated with a range of facility sizes. This technical paper documents the development and use the WETPOND model, which simulates the long term pollutant removal provided by a wet detention facility. Model input requirements include the physical characteristics of a wet detention pond and storm water pollutants, and a long term runoff array developed using SWMM. Pollutant removal is determined by incorporating an EPA procedure that addresses the physical process of "dynamic" and "quiescent" settling. This modeling approach allows the facility designer to estimate pollutant load reductions due to particle settling using a range of wet detention facility storage volumes.

INTRODUCTION

Implementation of recent State and Federal storm water management programs have placed a renewed interest in the development of innovative design technologies
t' related to the treatment of storm water runoff. In particular, the National Pollutant Discharge Elimination System (NPDES) storm water program requires that municipal separate storm sewer systems (MS4) provide treatment of storm water runoff to the “maximum extent practicable" (MEP). The Part 2 NPDES permit application requires that MS4's develop a storm water management program that reduces the impact of non-point source (NPS) pollution on receiving water bodies. In addition, the State of Florida has required local governments throughout the State to develop comprehensive plans that address the treatment of storm water runoff from existing development. Accordingly, storm water facility designers will be challenged in the future to create storm water treatment systems that capture runoff from existing development and remove the greatest amount of NPS pollutants, given the fixed amount of funds available to construct storm water facilities.

To comply with this new agenda, the storm water facility designer will need to employ design techniques that allow the prediction of NPS pollutant removal, given the "best" combination of treatment technologies and facility size. Pollutant removal goals and the availability of funds for capital improvement projects (CIPS) will vary with the drainage basin and the facility owner. Accordingly, the design of storm water treatment facilities using broadly applied technology based standards (e.g., detention of one inch of runoff) will have less application, since the facility designer should choose a combination of facility technologies and sizes that is most appropriate for the drainage basin under consideration. Only in this fashion can the facility designer seek to remove the greatest amount of NPS pollutants for the funds expended, or minimize the cost of treatment facilities given the pollutant removal goals of the drainage basin. This technical paper describes the creation and use of a Fortran computer program called WETPOND that simulates the pollutant removal characteristics of a wet detention facility. Pollutant removal is determined by incorporating an EPA design procedure (EPA,

1986) that addresses the physical process of "dynamic" and “quiescent" particle settling. WETPOND requires as input the physical characteristics of the wet detention facility and the NPS pollutants under consideration; and, an extended period runoff array created using the Storm Water Management Model (SWMM) (Huber, et.al., 1988). The WETPOND computer model, and the referenced EPA design technique, represent another "tool" that allow the proper selection and sizing of storm water treatment facilities.

METHODOLOGY

Progress in technology based applications is typically accomplished in increments that build upon the results and success of others. And, so it is with the subject of this technical paper. The development of WETPOND was based upon the research and subsequent results documented in an EPA report entitled "Methodology of Detention Basins for Control of Urban Runoff Quality" (EPA, 1986). In particular, this EPA Report describes specific methodologies that can be used to make planning level decisions in the design of infiltration and/or wet detention facilities, which are based partially upon the results of EPA's Nationwide Urban Runoff Program (NURP). Specific observations presented in this EPA Report include the following.

...... Studies conducted under the NURP program indicated detention and retention basins to be the most effective and reliable of the techniques examined for the control of urban runoff pollutant loads. The principal mechanisms that influenced pollutant. removals were either subsurface infiltration, or sedimentation."

and,

"A detention device installed at a specific location is necessarily of a fixed size and capacity. Storm water runoff, on the other hand, is highly variable. Any installation, therefore, will exhibit variable performance characteristics, depending on the size of the storm being processed ......

The first statement identifies the importance, and relative dominance, of sedimentation as the primary cause of pollutant removal in wet detention systems. The latter statement recognizes that the ability of a storm water facility to remove pollutants on an annual basis is directly related to the total storage capacity of the facility, the rate in which the runoff can be processed (treated), and the volume and timing of land surface runoff events that have occurred throughout the year. Accordingly, the ability of a treatment facility to remove pollutants during a particular runoff event is directly related to the occurrence and volume of preceding runoff events. If a facility's treatment volume already contains "untreated" storm water at the beginning of a new event, the ability of the facility to provide additional treatment has been diminished, since "dirty" water may be forced through the facility without having been treated. Given the above observations, the referenced EPA Report presents a probabilistic approach to the selection and sizing of recharge and wet detention facilities that allow the user to predict long term pollutant removal due to infiltration and sedimentation for specific hydrologic conditions. In particular, pollutant removal in wet detention facilities is described as a sedimentation process that occurs during "dynamic" and "quiescent" conditions. Dynamic settling is defined as occurring during the runoff event and is dependent upon the pond overflow rate and an efficiency factor that reflects the degree of pond short circuiting. Quiescent settling is defined as occurring during the interevent dry period when there is no overflow from the pond, and is dependent upon the pond surface area. Both types of settling are also dependent upon the settling velocity of the pollutant particles contained in the storm water runoff. It is not the intent of this technical paper to reproduce all pertinent portions of the EPA reference document. However, key equations that describe the removal of pollutants under dynamic and quiescent settling conditions, as used in the development of the WETPOND model, are provided below.

Rd = 1 - [1+ (1/n) x (Vs/(Q/A))]**(-n)

and,

Rq = [Vs x A x Tie] / Vp

where,

Rd = Dynamic Condition Pollutant Removal (fraction)
Rq = Quiescent Condition Pollutant Removal (fraction)
n = Pond Efficiency Parameter, (n = I is very poor, n = 3 is good and n > 5 is very good)
Vs = Particle Settling Velocity
Q = Discharge from Pond
A = Pond Surface Area
Q/A = Pond Overflow Rate
Tie = Interevent Time Period
Vp = Pond Volume

In **addition,** the equation that calculates combined removal (R) due to both dynamic and quiescent conditions is provided below. The form of this equation recognizes that removal due to quiescent settling (Rq) is applied only to that portion of the pollutant load not already removed by dynamic settling (I - Rd).

R = Rd + [Rq x (I - Rd)]

The methodology presented in the EPA Report incorporates a probabilistic approach to sizing storm water treatment facilities that characterizes local rainfall conditions using summary statistics, and employs land use coefficients to generate runoff volumes. These methods are not described herein, however, the EPA Report does acknowledges the following.

“There are other analysis methods available that can accomplish the same objective. EPA's Storm Water Management Model (SWMM) and the Storage, Treatment, Overflow Runoff Model (STORM) are both well documented simulation techniques that have seen extensive use ..... Since these simulators can avoid several of the simplifying assumptions of the probabilistic approach, the estimates they provide are likely to be somewhat more accurate projections ......

The WETPOND computer model employs the sedimentation pollutant removal mechanisms described in the EPA Report, and characterizes local meteorologic and hydrologic conditions using an extended period runoff array that is created using, SWMM. Accordingly, the WETPOND Model represents an improvement to the EPA probabilistic approach, allowing the user to incorporate the degree of accuracy required for a particular application. The runoff array input to WETPOND incorporates long term recorded rainfall data, and may be developed using the considerable simulation capabilities offered by SWMM. In addition, since SWMM has many potential uses in watershed analysis and the design of storm water systems, the WETPOND model offers the user a new method of employing SWMM runoff arrays that may have already been created.

RESULTS

The WETPOND model was tested using the results of a SV;MM modeling effort completed for the City of Jacksonville (ETM and CH2M HILL, 1993) and a range of typical storm water particle settling velocities (EPA, 1986). The SWMM runoff arrays used in this analysis were generated using a ten year sequence (1971-1980) of rainfall data recorded at the Jacksonville Airport; Green-Ampt parameter values related to A and D hydrologic soil groups (HSG) (Rawls, 1983); and, three different directly connected impervious areas, including 25, 60 and 75 percent. The particle settling velocities employed included 0. 009, 0.09, 0.46, 2. 1, and 20 meters per hour. (0.03, 0.3, 1.5, 7.0 and 65.0 feet per hour). Using Stokes Law (Barfield, 1981) it can be determined that these settling velocities represent particle diameters of approximately 0.0017, 0.0054, 0.012, 0.026, and 0.080 mm, respectively. Initially, it was assumed that each of these five particle categories represented 20 percent of the total particle mass present in the storm water. A range of wet detention storage volumes (Vs) were then analyzed, which were normalized to the average annual volume of runoff (Vr) generated by a 40 hectare (100 acre) drainage basin. The results of this initial analysis is presented on Figure 1, which presents a range of normalized storage volumes (Vs/Vr) versus the fraction of solids removed during dynamic and quiescent settling conditions. Also presented is the total fraction of solids removed, which is determined using the equation presented previously (R Rd + [Rq x (1 - Rd)]). Given the settling velocities presented above, Figure I illustrates that the fraction of solids removed due to dynamic settling is greater than that provided by quiescent setting for "smaller" wet detention storage volumes ((Vs/Vr) < 0.5). As the wet detention storage volume increases, however, the fraction of solids removed due to quiescent settling becomes greater, and more important to the total fraction removed. Figure I indicates that pollutant removal due to dynamic settling is effective in removing a large portion of the total pollutant load,' even for relatively small wet detention facilities. However, quiescent settling and larger storage volumes are required if greater solids removal is specified. The actual fraction of solids removed is highly dependent on the size distribution of solid particles present in the storm water runoff. This was demonstrated by executing the WETPOND model using a single settling velocity. The results of this analysis are presented on Figures 2, 3 and 4, which were created using particle settling velocities of 0.009, 0.46 and 20 meters per hour (0.03, 1.5 and 65 feet -per hour), respectively. As presented on these figures, the removal of smaller particles, with smaller settling velocities, requires larger wet detention storage volumes, because quiescent settling becomes more important. Also, the removal of larger particles can be accomplished with smaller wet detention volumes, since dynamic removal dominates the total solids- removal.

CONCLUSIONS

In the future, the design of storm water treatment facilities for existing developed areas will require that new methods of analysis are employed. Designers will need to select and size the most appropriate combination of storm water treatment facilities that either maximize the amount of pollutants removed given fixed funds, or minimize facility cost for fixed pollutant removal goals. The method of wet detention facility design presented in the referenced EPA report is a useful tool that can assist in these more detailed analyses. This analysis method employs a probabilistic approach that allows the user to predict solids removal due to sedimentation, given specific facility design parameters. The WETPOND computer model simulates the dynamic and quiescent settling mechanisms defined in the EPA report, but incorporates SWMM runoff arrays that can more accurately represent watershed hydrology and hydraulics. In addition, WETPOND allows the user to identify the significance of dynamic and/or quiescent settling to the removal of specific particle groups, which may be associated with particular pollutant types. The usefulness of the EPA method, and the WETPOND model, will increase as more comprehensive literature values become available that characterize the solids present in storm water runoff and their relationship to pollutants of concern. Through the use of tools such as the WETPOND model, the facility designer can gain further insight into the proper selection and sizing of storm water treatment facilities.

REFERENCES

Barfield, B.J., Warner, R.C., and Haan, C.T. "Applied Hydrology and Sedimentology for Disturbed Areas." Stillwater, OK: Oklahoma Technical Press. 1981.

England, Thims, and Miller, Inc, and CH2M HILL. "City of Jacksonville, Florida, Part 2 Submittal, NPDES Municipal Storm Water Permit Application." March, 1993.

Environmental Protection Agency (EPA). "Methodology for Analysis of Detention Basins for Control of Urban Runoff Quality." EPA440/5-87-001, 1986.

Huber, W.C., and R.E. Dickerson. "Storm Water Management Model, Version 4: User's Manual." University of Florida and the Environmental Research Laboratory, USEPA. 1988.

Rawls, J.R., D.B. Brakensiek, and **N.** Miller. "Green-Ampt Infiltration Parameters from Soils Data." ASCE Journal of Hydraulic Engineering 109(l), 62-70. 1983.

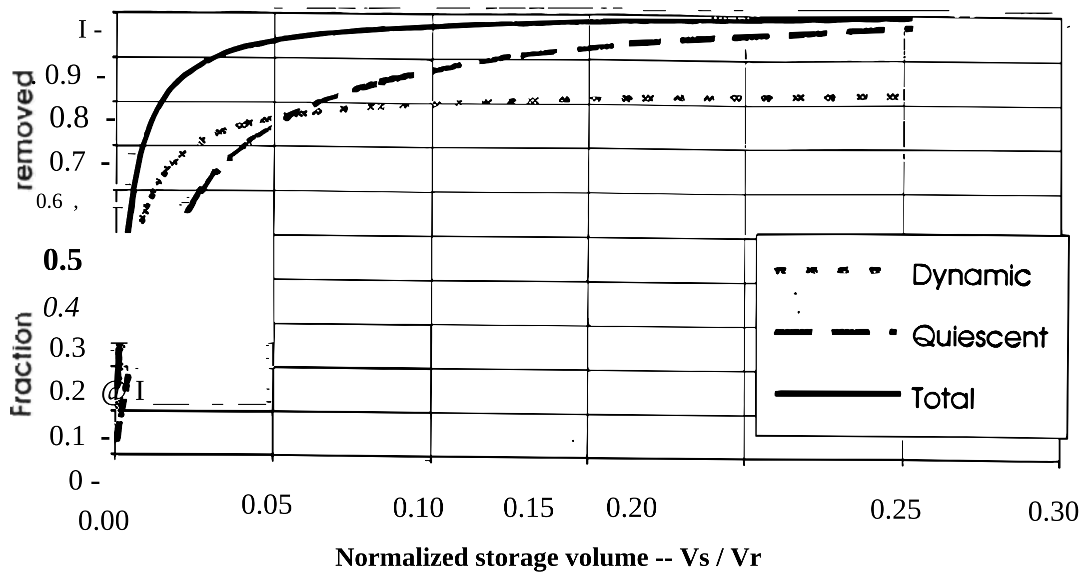

Figure 1. Typical WETPOND solids removal

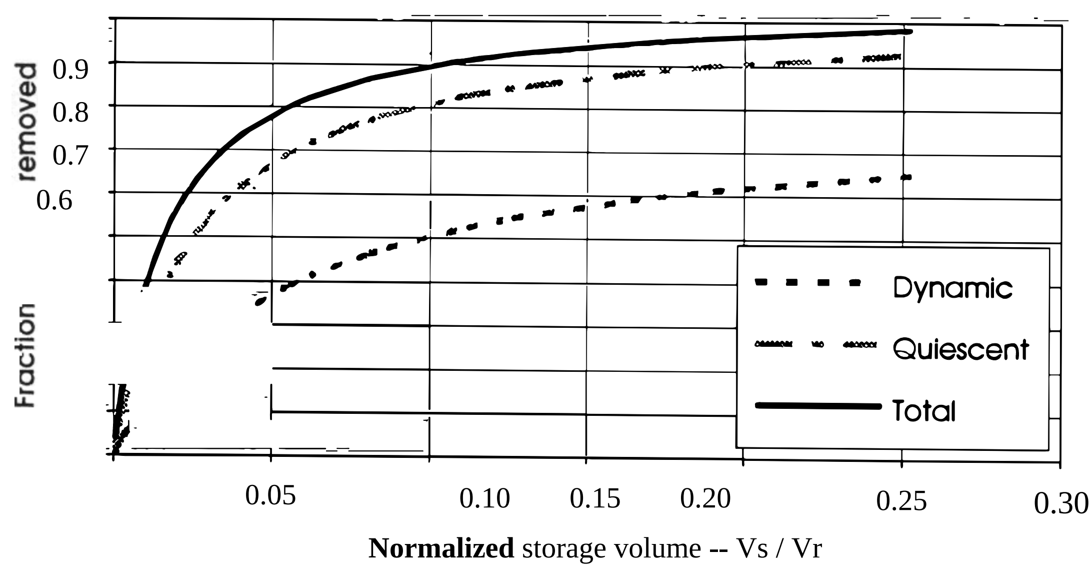

Figure 2. Solids removal for settling velocity = 0.009 m/hr (0.03 ft/hr)