CRITICAL ASSESSMENT OF MANAGEMENT PRACTICES AND POLICIES FOR STORMWATER AND SEDIMENT PONDS IN SOUTH CAROLINA

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Abstract. Local regulations in South Carolina must comply with SCDHEC standards, which require stormwater detention and sediment retention ponds be designed based on runoff from 2- and 10-year 24-hour rainfall events. Inadequate pond performance, particularly during more frequent, shorter duration and high intensity events, raises questions about the adequacy of the design standards. As one approach to answer these questions, a parametric study was conducted to evaluate pond performance during storms other than the regulatory 2- and 10-year 24-hour events, specifically for variable frequency, depth, and duration storms, and long-term. Results demonstrate stormwater and sediment ponds designed in accordance with current policies are not sufficient to control downstream flooding and channel aggradation-degradation. For better control, 24-hour extended detention of the 1-year 24-hour storm should be implemented. The study results also suggest stormwater detention and sediment retention ponds should be designed to control flow and sediment for storms with a return period equal to or less than 1-year.

INTRODUCTION

Ponds are used extensively throughout the United States to regulate increases in runoff and sediment resulting from urban development. Local regulations in South Carolina must comply with SCDHEC standards, which require stormwater detention and sediment retention ponds be designed based on runoff from 2- and 10-year 24-hour rainfall events. There is growing suspicion many of these ponds are not performing acceptably, as indicated by greater incidence of downstream flooding and channel scouring, siltation, and widening. Many of these problems occur during more frequent, shorter duration rainfalls that produce high peak flowrates and result in greater erosion and sediment transport than is predicted to happen during the design 24-hour rainfall events. One point of evidence is the number of complaints and lawsuits by property owners downstream of ponds designed according to current regulations.

To assess the adequacy of contemporary design standards, and thereby to allay or provide further support for the aforementioned suspicions, a parametric study was performed to assess pond performance for different return period, depth and duration storm events, variable water and sediment loadings, and life cycle performance. Single event simulations were used to study peak flow control, sediment trapping efficiency, and peak effluent settleable solids. Continuous simulations using 5-year sequences of daily rainfall were used to study pond life cycle.

PARAMETRIC STUDY

The main purpose for the parametric study was to generate a pond performance database that was analyzed to evaluate contemporary stormwater management policies and practices. To obtain a representative data set, simulations were performed for pre-development (no control), construction phase (control) and post-development (control) conditions. Thirty-five events covering a range of return periods, rainfall depths and durations were chosen for event-based simulations. Rainfall data were taken from NOAA Atlas 14 (Bonnin and others, 2006) for northern Richland County, South Carolina. Seven design storms with return periods of 1, 2, 5, 10, 25, 50 and 100-years, rainfall depths ranging from 1.54 inches to 8.42 inches, and five design storm durations of 1, 3, 6, 12 and 24-hours were chosen. For the continuous simulations, USClimat 2.0 (Hanson and others, 1994) was used to generate the 5-year rainfall sequences.

Stormwater detention and sediment retention ponds were designed for two hypothetical watersheds based on 2- and 10-year 24-hour design storm events. Each pond was located between the watershed outlet and the downstream channel. Watershed physical characteristics such as area, flow length, slope, and land use conditions during pre-development, post-development, and construction phase were modeled after a watershed in northern Richland County, South Carolina undergoing land use change from mixed forest and pasture to single family residential. Runoff hydrographs were simulated using the SC Synthetic Unit Hydrograph Method, which incorporates the NRCS curve number runoff model and the two parameter gamma function unit hydrograph. Curve numbers and peak rate factors (PRF values) were chosen for watershed land use and soil types.

Two soils common in northern Richland Country, Pelion (HSG-B) and Nason (HSG-C), were selected as the watershed soils. Soil erodibility factors were taken from the SCDHEC South Carolina Stormwater Management and Sediment Control Handbook for Land Disturbance Activities (SCDHEC 2003). CP factors of 0.01, 0.1 and 1.2 were chosen for pre-development, post-development and construction phases, respectively. Eroded grain size distribution curves were generated using equations developed for the CREAMS program (Foster and others, 1985). An unlined channel with constant trapezoidal cross-section was considered downstream of each pond. Channel length, width, depth, longitudinal and side slopes, roughness coefficient, base flow, and physical properties of bank and bed materials were the same for all scenarios.

The stormwater detention and sediment retention ponds were designed such that their post-development peak outflow rates for 2- and 10-year 24-hour design storm events were exactly equal to the watershed peak runoff for pre-development conditions. Multiple ponds were evaluated, but to allow direct comparison of different pond types, one stormwater detention pond and one sediment retention pond were designed for the same watershed size and characteristics, and had the same pond size, shape, depth and side slopes.

DRAIN:HYDRO 2.0

Simulations were performed using the Drain:Hydro 2.0 computer program (Huda and Meadows, 2007). Among other features, this program has algorithms to simulate runoff hydrographs and sedigraphs; route them through user prescribed stormwater and sediment ponds; account for net sediment delivery from the contributing watershed; modify the grain size distribution; evaluate sediment pond performance in terms of trapping efficiency, peak effluent settleable solids and net accumulation; route outflow hydrographs and sedigraphs through downstream channels; and calculate sediment load, channel bed aggradation-degradation, and channel bank erosion and widening.

The major components for the program include: a stand-alone ArcGIS tool; an upgraded drainage system simulation program (Drain:Hydro, Meadows, 1986); process-based stormwater pond routines; SEDIMOT II erosion and sediment pond algorithms (Wilson and others, 1982); daily weather simulator (USClimat, Hanson et al, 1994); long-term pond performance and life-cycle analysis algorithm; and a 1-D flow, channel evolution and sediment transport model. The channel evolution algorithm draws on CONCEPTS, a program developed at the USDA Sedimentation Laboratory to simulate channel degradation and widening (Langendoen, 2000).

STORMWATER DETENTION POND PERFORMANCE

To remove scale effects and to provide more meaningful assessment of pond performance, the respective performance data were normalized by dividing by the corresponding predevelopment values. In the following discussion, D-hour refers to storm durations less than 24 hours. The following discussion references the performances of the comparison stormwater and sediment ponds.

Peak Outflow Rate Control

Based on the normalized post-development and construction phase peak outflow rates, it was observed the stormwater detention pond controlled the peak outflow rates for 2 through 10-year 24-hour design storms but not for any duration 1-year event nor the 25, 50 and 100 year 24-hour events. Post-development peak outflow rates for 1-hour storms were 1.1 to 1.5 times higher than pre-development peak rates for the 1-year 24-hour event. The pond did not control peak flow rates at or below predevelopment levels for any of the 1-year storms.

Construction phase peak outflow rates for n-year D-hour storms, except the 50- and 100-year 1-hour storms, were higher than the pre-development peak rates for n-year 24-hour storms. Peak outflow rates for the 1-year storms were 1.25 to 2.50 times higher than the pre-development n-year 24-hour storms.

The detention pond performance in reducing hydrograph peak for post-development and construction phase was higher for shorter duration storm events.

Runoff Volume Control

Normalized post-development volumes for n-year 12 and 24-hour, and 1 through 10 year 6-hour storms were higher than pre-development conditions. Post-development volumes for 1-year 6, 12, and 24- hour storms were approximately 1.3 to 2.2 times higher than the pre-development volumes for n-year 24-hour storms.

Except for 10 to 100-year 1 and 3-hour storms, construction phase outflow volumes for all storms were higher than the pre-development n-year 24-hour storms. Construction phase volumes for 1-year D-hour storms ranged from 1.5 to 3.5 times greater than the pre-development volumes for n-year 24-hour storms. Post-development and construction phase outflow volumes were much higher than pre-development volumes due to the increased imperviousness for post-development conditions and bare soil condition created by land disturbance activities during construction phase.

Sediment Control

The large runoff volumes and peak outflow rates from post-development and construction phase conditions produced more eroded sediment mass than the pre-development condition. During n-year D-hour storms, except 1-hour storms, post-development and construction phase sediment masses were much higher than the pre-development condition during 24-hour storm events. Post-development sediment masses for 1-year storms, except 1-hour storms, were approximately 4 to 7 times higher than the pre-development condition for n-year 24-hour events.

Similarly, construction phase sediment masses for 1-year D-hour storms were approximately 6 to 55 times higher than pre-development sediment masses for n-year 24-hour storms. Land disturbance activities during construction phase created more erosion during all thirty-five storm events.

Higher sediment trapping efficiencies were observed for the two soils used in the study, Pelion (loamy sand, HSG=B) and Nason (silty loam, HSG=C), for longer duration n-year storm events under post-development and construction phase conditions. Post-development sediment trapping efficiencies varied from approximately 87% to 92% for Pelion soil and from 66% to 78% for Nason soil. Construction phase sediment trapping efficiencies varied from approximately 89% to 93% for Pelion soil and from 68% to <80% for Nason soil.

The post-development peak settleable solids concentrations were below 0.5 ml/l for Pelion soil, ranging from < 0.01 to 0.35 ml/l. For Nason soil, the post-development peak settleable solids concentrations for 10-year 24-hour, and 25, 50 and 100-year D-hour storms were above 0.5 ml/l.

For n-year D-hour storms, except 1-hour storms, the construction phase peak settleable solids concentrations were higher than 0.5 ml/l for both Pelion and Nason soils. It must be noted that achieving 80% sediment trapping efficiency does not guarantee the peak settleable solids concentration will be less than 0.5 ml/l.

Downstream Channel Protection

This pond controlled channel peak flow rate and depth for all storms, except the 1-year and 25 to 100 year 24-hour storms. Post-development channel peak flow rates and depths for 1-year D-hour storms were approximately 1.25 to 1.80 and 1.05 to 1.50 times higher than for 24-hour storms under pre-development conditions. It must be emphasized this pond did not control channel peak flow rates and depths for any of the 1-year storms.

For all D-hour storms, except the 100-year 1-hour storm, construction phase channel peak flow rates and depths were approximately 2.05 to 2.65 and 1.30 to 1.60 times higher than the pre-development condition for corresponding 24-hour storms. It was reasoned higher post-development and construction phase channel peak flow rates and depths were responsible for increased bank erosion and bed aggradation-degradation.

Post-development cumulative average channel bank widening for 1 to 5 year 1-hour storms and n-year 3 to 24 hour storms were much higher than for the pre-development 24-hour storms. Cumulative average channel bank widening for 1-year storms ranged from 2 to 6 times greater than for the pre-development 24-hour storms. Construction phase cumulative average channel bank widening for 1-year storms varied from 4.60 to 9.50 times higher than the pre-development 24-hour storms.

It was found that significant post-development and construction phase bank erosion/widening and bed erosion-deposition occur in comparison to the pre-development condition. The 50-year and 100-year D-hour storms created flooding problems in the downstream channel.

SEDIMENT RETENTION POND PERFORMANCE

Peak Flow Rate Control

The pond controlled peak outflow rates for 2 through 10 year 24-hour design storms but not for 1-year D-hour, 25-year 12 through 24 hour, 50-year 6 through 24 hour, and 100-year 3 through 24 hour storms. Post-development peak rates for 1-year storms were 1.1 to 1.5 times higher than the pre-development n-year 24-hour storms. Similar to the stormwater detention pond, the pond did not control peak flow rates for 1-year storms.

Construction phase peak rates for D-hour storms, except the 5-year 1-hour storm, were higher than the pre-development peak rates for 24-hour storms. Peak outflow rates for the 1-year storms were 1.75 to 2.00 times higher than for pre-development 24-hour storms. The sediment retention and stormwater detention ponds provided similar peak outflow rate control for 1 through 25 year return period storms.

Runoff Volume Control

Post-development volumes for n-year 12 to 24 hour and 1 through 10 year 6-hour storms were higher than for the pre-development 24-hour storms. Post-development volumes for 1-year 6 through 24 hour storms were approximately 1.3 to 2.2 times higher than pre-development volumes for other return period 24-hour storms.

Construction phase outflow volumes for n-year D-hour storms, except 10 through 100 year 1-hour storms and 100-year 3-hour storms, were much higher than for the pre-development 24-hour storms. Outflow volumes for 1-year D-hour storms were 1.5 to 3.5 times higher than pre-development volumes for n-year 24-hour storms. The post-development and construction phase outflow volumes were much higher than pre-development volumes for most storms. Both sediment and stormwater ponds provided similar volume control.

Sediment Control

Post-development and construction phase sediment masses for n-year D-hour storms, except 1-hour storms, were higher than for the pre-development 24-hour storms. The post-development sediment masses for 1-year 3 to 24 hour storms were approximately 3 to 6.5 times higher than for 24-hour storms during pre-development.

Construction phase sediment masses for 1-year storms were 5 to 125 times greater than for all of the pre-development 24-hour storms. Post-development sediment trapping efficiencies varied from approximately 91% to 98% for Pelion soil and from 72% to 86% for Nason soil.

Construction phase sediment trapping efficiency for all storms varied from approximately 92% to 97% for Pelion soil and 71% to 90% for Nason soil. This pond met 80% sediment trapping efficiency for 1 through 5 year D-hour and 10-year 24-hour storms for Nason soil. The post-development peak settleable solids concentrations were below 0.5 ml/l for Pelion soil and ranged from < 0.01 to 0.34 ml/l. For Nason soil, the post-development peak settleable solids concentrations for 25-year 24-hour, 50-year 6- hour, 50-year 12-hour, 50-year 24-hour and all 100-year storms were above 0.5 ml/l.

The pond performance failed during construction phase when the peak settleable solids concentrations for all storms longer than 1 hour duration were higher than 0.5 ml/l for both soils. Peak settleable solids concentrations were as high as 4.4 ml/l and 9.3 ml/l for Pelion and Nason soils, respectively.

Controlling Secondary Effects

Hypothetically, it is believed that if it is possible to maintain pre-development and post-development (control) hydrograph shape, volume and timing, then it will be possible to control the secondary effects of pond outlets on downstream channel. An attempt was make to investigate this hypothesis. A sediment retention pond was designed in such a way that permanent pool volume equaled the difference between the pre- and post-development runoff volumes for a 1-year 24-hour storm. For water quality purposes, current SCDHEC regulations suggest this storage volume shall be designed to accommodate at least one-half inch of runoff from the entire watershed. This permanent pool volume should not be less than water quality volume.

The main goal behind this idea was to maintain post-development runoff hydrograph volume at the pre-development level. Results show the post-development hydrograph shape, volume, and time to peak were very close to the values for pre-development condition. Little variations of sediment transport rate and sediment transport capacity were observed during the period of peak flow. However, due to the longer and more elevated recession limb of the post-development outflow hydrograph, the flow depths and velocities in the channel were higher for a longer period of time, which created more bank erosion/widening compared to pre-development condition. In post-development condition, more bed erosion occurred at the channel entrance immediately downstream of the pond outlet.

CONCLUSIONS

Conclusions based on the findings of this study are: (1) not all stormwater and sediment ponds designed in accordance with current policies and practices are sufficient to control downstream flooding and channel aggradation-degradation. During variable frequency, depth, and duration storm events, stormwater and sediment ponds frequently violate regulations. The 2- and 10-year 24-hour controls are not sufficient to protect downstream channels. To better control downstream flooding and channel aggradation-degradation, 24-hour extended detention of the 1-year 24-hour controls should be implemented. (2) Sediment retention ponds provide better performance than stormwater detention ponds in terms of sediment trapping efficiency and peak effluent settleable solids concentration. They also provide better channel protection. (3) Sediment retention ponds can be designed to maintain post-development (control) hydrograph shape, volume, timing and more importantly sediment transport capacity at pre-development levels. The permanent pool volume should equal the difference between post-development and pre-development runoff hydrograph volumes for a 1-year 24-year storm event. This volume should be drained over 24 hours following cessation of rainfall. To meet current SCDHEC regulations for water quality design, this volume should not be less than one-half inch of runoff from the entire watershed.

RECOMMENDATIONS

More frequent, variable depth and shorter duration storm events are responsible for the majority of runoff and sediment washoff annually. Therefore, smaller storm events should be the greater concern for water quality protection. Larger storm events, because they occur infrequently, contribute relatively little to the average annual sediment load. Since storm events vary dramatically in magnitude and duration, stormwater detention and sediment retention ponds should be sized based on their performance during runoff from storms having return period equal to or less than 1-year.

LITERATURE CITED

(1) Bonnin, G. and others. 2006, Precipitation Frequency Atlas of the United States, NOAA Atlas 14, 1(4), Silver Spring, Maryland.

(2) Booth, D. B. and R. Jackson, 1997. Urbanization of Aquatic Systems: Degradation, Thresholds, Stormwater Detection, and the Limits of Mitigation, Journal of the American Water Resources Association, Vol. 33, No. 5, pp 1077-1090.

(3) Foster, G. R. and L. D. Meyer, 1972. A Closed-form Erosion Equation for Upland Areas. Sedimentation: Symposium to Honor Professor H. A. Einestein, Ed. Shen, Fort Collins, Colorado.

(4) Hanson, C. L. and others, 1994. Microcomputer Program for Daily Weather Simulation in the Continuous United States, Users Manual. U. S. Department of Agriculture, Agricultural Research Service, ARS – 114.

(5) Huda, M. K., 2007. Parametric Study to Evaluate the Adequacy of Current Design Practices and Policies for Stormwater and Sediment Ponds. Ph.D. Dissertation, Submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Civil Engineering, University of South Carolina.

(6) Huda, M.K. and Meadows, M.E. (2007). Drain:Hydro 2 – A Windows Based Stormwater Drainage System Simulation Program with Added Features for GIS, Stormwater BMPs, Sediment Ponds, and Channel Erosion and Sediment Transport," Dept. of Civil and Environmental Engineering, Univ. of South Carolina.

(7) Langendoen, E. J. 2000. CONCEPTS– Conservational Channel Evolution Model and Pollutant Transport System". Research Rep. No. 16, US Department of Agriculture, Agriculture Research Service, National Sedimentation Laboratory, Oxford, MS.

(8) Meadows, M. E. 1986. Meadows, M.E. (1986). "Drain:Edge - Stormwater Simulation and Design Model," C D Software, Inc., Columbia, SC.

(9) Meadows, M.E (1996). "Drain:Hydro - Stormwater Drainage System Simulation Program," Dept. of Civil and Environmental Engineering, Univ. of South Carolina.

(10) South Carolina Department of Health and Environment Control (SCDHEC), 2003. South Carolina stormwater management and sediment control handbook for land disturbance activities, Bureau of Water, Office of Ocean and Coastal Resource Management.

(11) The State of South Carolina, 1991. The Stormwater Management and Sediment Reduction Act (Stormwater Act), Section 48-14-10.

(12) Wilson, B. N. and others 1982. A Hydrology and Sedimentology Watershed Model: Part II: Sedimentology Component. Trans. of the ASAE, 27(5), 1378-1384.