Models of wet basin design response with residence time metrics for presumptive guidance

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Highlights

- This abstract is based on the following publication: Spelman, D., Sansalone, J. (2021). Models of Wet Basin Design Response with Residence Time Metrics for Presumptive Guidance. Journal of Environmental Engineering. 147(12) doi.org/10.1061/(asce)ee.1943-7870.0001931
- A novel modeling framework coupling the Stormwater Management Model, computational fluid dynamics, and stepwise-steady was demonstrated for the prediction of wet season basin transport behaviour
- Detention time alone is insufficient as a presumptive treatment indicator for wet basins based on wet season constituent residence time and the effect of internal hydrodynamics

Introduction

Improved understanding of transport and treatment processes within wet basins is needed to further the design guidance, regulatory framework, and site-specific expected treatment performance of these common systems. This is made difficult by the complex, unsteady set of flow conditions and hydrodynamics within basins coupled with complex treatment processes that are ill-understood due to the inherent difficulties of full-scale basin monitoring campaigns. Traditional modeling efforts provide limited predictive capability in terms of comparison of design alternatives and site-specific treatment of basins. Novel continuous modeling methods utilizing computational fluid dynamics (CFD) can provide the predictive capability and increased understanding necessary to move the engineering practice forward and provide much needed guidance on wet basins. This study examines the interface between these entangled fronts of wet basin design, presumptive treatment performance metrics, constituent transport and load-response behavior, and predictive capability through the introduction of a novel modeling methodology for continuous simulation of wet basins and through a robust modeling exercise.

Through a series of models of load-response for scaled basin designs, as geometrically patterned from an existing basin, this study examines the behavior of basins and tests models in the context of geometrics (sizing, inlet configuration, baffles). Presumptive guidance for basin sizing is examined based on residence time (RT) as a common surrogate for the treatment of aqueous or PM-bound constituents. This study examines the sensitivity of modeled RT for a wet basin subject to wet season loadings.

Methodology

An existing basin with a 112-hectare watershed was modeled in this study. The Stormwater management model (SWMM) was used to generate inflows for a simulated wet season. Simulated wet season RT results were obtained for 7 hypothetical alternative designs of this basin, as shown in Figure 1. The existing basin was modeled with and without baffled retrofit, as shown in Figure 1. The 14-day basin was modeled with a multiple-inlet and combined inlet configuration. Constituent RT was simulated within each basin throughout the wet season using a novel modeling framework. A steady-flow CFD model was created for each basin design. For a series of 11 steady flowrates, covering the range of wet season flowrates simulated by SWMM, a 3D flow-field was modeled in CFD providing a complete picture of the internal hydrodynamics across 8-19 million computational cells. Tracer particles were then simulated through this flow field to produce a set of steady-flow residence time distributions (RTD). The steady-flow dataset from CFD was then combined with the implicit solution stepwise steady (IS^3) model developed by Spelman and Sansalone (2017) to simulate constituent RT throughout the wet season. The IS^3 method divides the 122-day wet season into 10-minute time steps, predicting the RTD experienced by constituents entering the basin at each time step, and aggregating eluted constituents throughout. This modeling approach has previously only been applied to small-scale treatment devices such as hydrodynamic separators for individual storm events. Long-term simulation of basins combining SWMM, CFD, and IS^3 is a novel contribution.

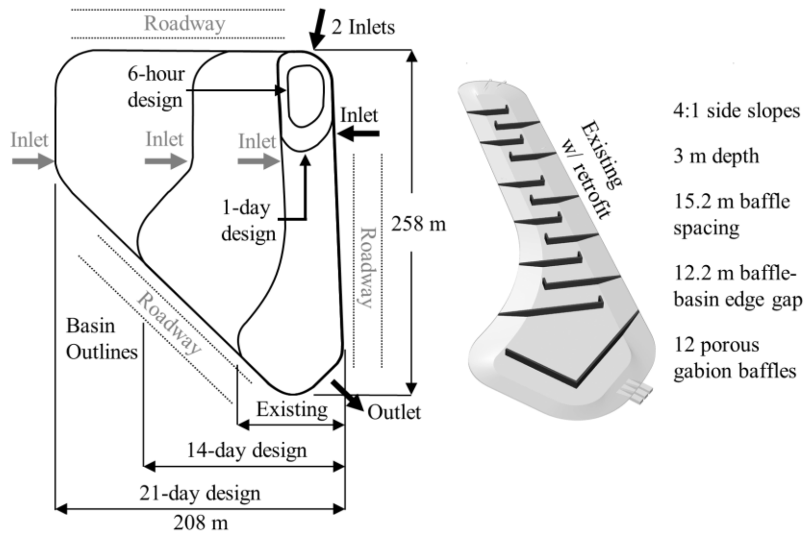

Figure 1. Dimensioned outline of modeled basins and isometric view of the retrofitted existing basin

Results and discussion

Modeled RTD indices throughout the wet season are shown for all 7 basin designs in Figure 2. The RT experienced by constituents travelling through the basin varies considerably throughout the wet season according to the unsteady flows entering the basin; thus, a distribution for each RTD index (t_{10}, t_{50}, and t_{90}) is provided. Median (t_{50}) constituent RT was consistently shorter than the mean wet season hydraulic residence time (HRT) (85-99% of HRT) for all basins. The addition of internal baffling via basin retrofit resulted in a 42% increase in median RT without any increase in basin size. This is due to an improvement in volumetric utilization and decrease in short-circuiting behaviour. Similarly, the multiple outlet design of the 14-day basin yielded a 115% increase in median RT. In both cases, the effect of internal hydrodynamics resulted in a shift of the entire RTD, rather than a reshaping of the RTD that would be expected from a change in the Morrill dispersion index (MDI). This suggests that substantial dead-zones exist in the 14-day combined inlet and existing basin without retrofit designs.

Given the significant cost of land for wet basins, optimizing internal hydrodynamics for maximum constituent RT in a given footprint is imperative. Length/width ratios alone may be insufficient as design guidance. Given the significance of geometry and internal baffling, the discrepancy between constituent RT and designed HRT, and the variability of RT throughout the wet season, HRT alone is an insufficient presumptive indicator of basin treatment performance.

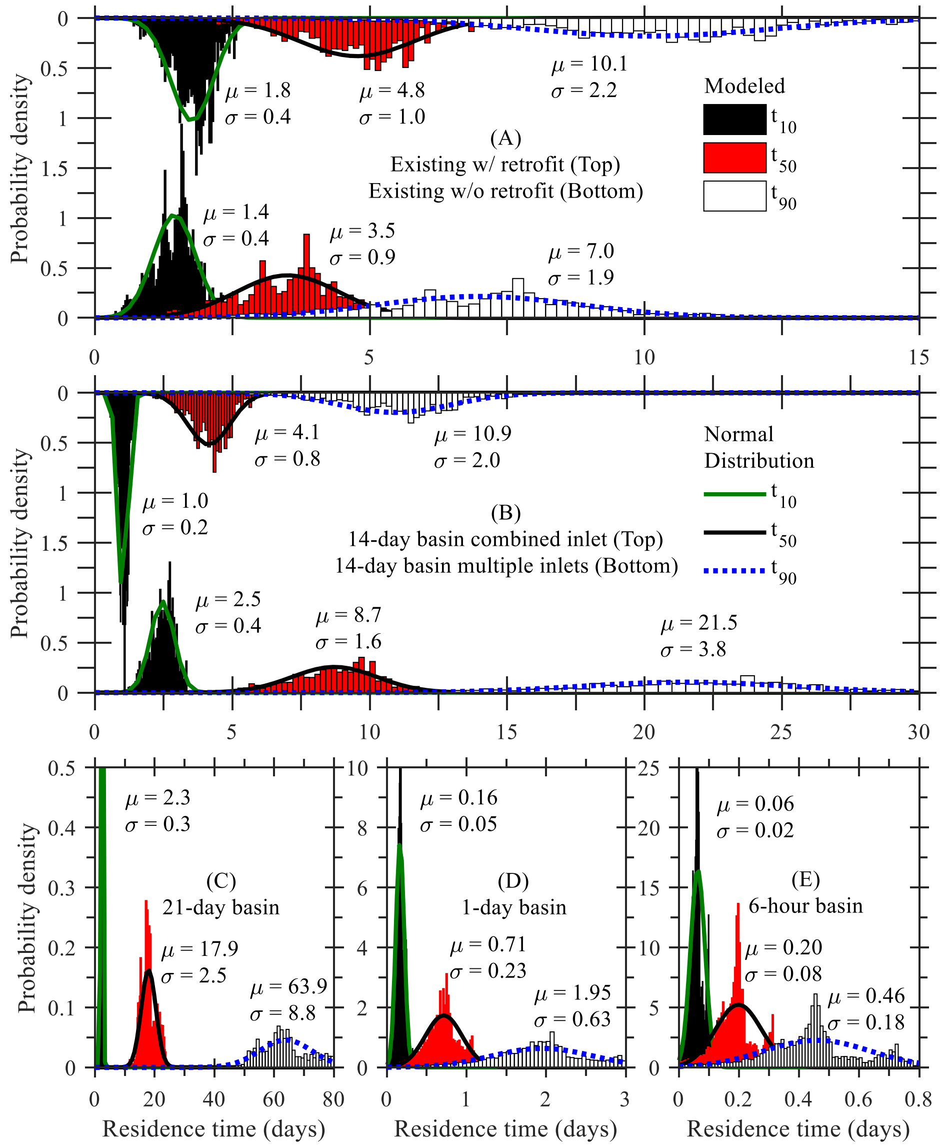

Figure 2. Frequency distributions of modeled wet season residence time distribution (RTD) metrics. t_x represents the elapsed time at which x percent of elution has occurred. Fitted normal distributions are plotted alongside modeled data with mean (μ) and standard deviation (σ) values provided. Results shown for the CFD with implicit solution stepwise steady (IS3) model.

Conclusions and future work

Based on the modeled results, wet season HRT alone is an insufficient predictor of basin performance. Basin geometry, inlet configuration, and internal retrofits that avoid short-circuiting should be considered alongside basin size in design and regulation of basins. Given the spectrum of constituent RT modeled in the studied basins, an event-based approach to basin monitoring may be problematic. The novel modeling framework demonstrated in this study shows promise in providing fundamental predictive capability in simulating long-term unsteady basin transport behaviour. Future studies coupling this approach with decay models for treatment are of interest.

References

Spelman, D., and Sansalone, J. J. (2017). "Methods to model particulate matter clarification of unit operations subject to unsteady loadings." Water Research, Elsevier Ltd, 115, 347–359