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Predicting Hydrology in Wetlands Designed for Coastal Stormwater Management

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Abstract. *Detention ponds are currently accepted as stormwater best management practices (BMPs) in coastal South Carolina. These ponds are typical catch basins for stormwater piped directly from impervious surfaces in many residential and resort areas. Nutrients often concentrate in the ponds and contribute to eutrophication within the ponds and downgradient estuaries. A supplementary BMP is proposed that would augment nutrient attenuation in these urbanized watersheds and subsequently reduce the potential for nutrients to enter adjacent estuaries. A created wetland was designed to border an existing detention pond on Kiawah Island, SC, providing*

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a vegetated buffer with increased retention time for stormwater flows from upland residential and recreational uses toward ecologically sensitive receiving estuarine waters. The overall objective of the project was to determine the feasibility of a created wetland as a retrofit option. The unique design incorporates aspects of both subsurface and surface-flow constructed wetlands for processing nutrient-enriched stormwater and groundwater, focusing on encouraging denitrification for the reduction of nitrate fluxes into the detention pond. For hydrologic evaluation, a continuous water balance model was developed using STELLA® software to determine the hydrologic capacity and stormwater management potential of two selected wetland designs. This paper describes the evaluation process and assesses the design concept in terms of stormwater management.

Keywords. Stormwater wetlands, Nitrate, Ammonium, Residence time, Wetland design, Golf course.

Introduction

Along the South Carolina coast, detention ponds are an accepted best management practice (BMP) for stormwater management. Stormwater ponds are typically designed to capture runoff from a certain size storm event and for sediment storage. These ponds tend to be located in urban and resort communities, where they often accumulate rather than attenuate nutrients (Lewitus et al., 2003) entering the ponds via stormwater, surface runoff, and groundwater (Bunker 2004). Nutrient loading into the ponds often leads to eutrophication, algal blooms, low dissolved oxygen levels, and fish kills (Lewitus et al., 2003). Because these ponds were designed specifically for managing stormwater quantity and not necessarily quality, the development of supplemental stormwater buffers for water quality improvement is essential. This study describes the development of a modelling tool used in designing a wetland as a supplemental BMP for processing nutrient-rich stormwater.

Eutrophication in coastal detention ponds is associated with high nitrogen (N) levels, high biological oxygen demand, strong odors, algal blooms of sometimes harmful species, and fish kills (Lewitus et al., 2003, 2004). The high N loads that contribute to eutrophication are the result of two main changes on the landscape – inhibition of the natural ecological processing of runoff due to deforestation and construction of impermeable surfaces, and nutrient fertilization and irrigation for turf and garden management (Lewitus and Holland, 2003; Holland et al., 2004). In addition, ponds as currently designed are ineffective at removing nutrients, instead acting to accumulate them to occasionally hypereutrophic levels (Lewitus et al., 2003).

The nutrient of greatest concern on the coast is N because marine and estuarine systems are generally N-limited (Poe et al. 2003) and therefore react strongly to N additions (Casey and Klaine, 2001). Under more natural conditions, the biogeochemical N cycle would prevent large amounts of mineral N (NO_3^- , NH_4^+) from entering estuarine and marine systems. Currently, the reduced processing capacity of surrounding landscapes contributes to N accumulation in the ponds. Due to artificial watershed drainage, anaerobic conditions necessary for denitrifying bacteria have been reduced, resulting in increased mineral N entering the ponds. Instead of denitrification reducing N, N is used and recycled by the pond biota in the form of NH_4^+ , a form that cannot leave the system via denitrification without first being nitrified. Also, the ponds as designed do not have significant aerobic conditions for nitrification and, therefore, N accumulates.

Efforts are underway to improve water quality along the coast of South Carolina by restoring denitrification capacity to stormwater drainage systems that discharge into estuarine systems. The contribution of stormwater and groundwater to pond N enrichment has been quantified for two target watersheds and detention ponds (Bunker, 2004) and the potential denitrification capacity of terrestrial soil and pond sediments have been determined (Drescher et al., 2006). In addition, a constructed wetland was designed for use as a retrofit option for improving water quality in coastal ponds (Strosnider 2005). This effort is a demonstration of the use of this design as an effective supplementary BMP.

Numerous studies have demonstrated the effectiveness of constructed wetlands at reducing N loads in effluent (Hammer and Knight, 1994; Kadlec and Knight, 1996; Kohler et al. 2004). The challenges for this project were to develop a practical retrofit design within the tough spatial constraints of an existing residential community and resort and to create a simulation model to predict hydrologic performance and behavior of the proposed constructed wetland.

Although steady state models are reliable for predicting hydrologic performance of constant flow wetlands, continuous modeling was thought to be a more effective tool in predicting hydrologic

behavior of stormwater wetlands because the latter wetland type receives highly irregular flows (Konyha et al. 1995). Accurate characterization of hydrologic behavior is a critical step in the design of a highly functional wetland because an important factor in wetland functionality, particularly as it relates to N processing, is the establishment of an appropriate hydrologic regime with sufficient residence time (Konya et al., 1995; Kadlec and Knight, 1996; Mitsch and Gosselink, 2000; France, 2003). Through wetland processes, the removal of N from effluent is logarithmically related to residence time (Kadlec and Knight, 1996).

Previous simulations of wetland and shallow water table hydrology have used as models DRAINMOD (Skaggs, 1978), MODFLOW (McDonald and Harbaugh, 1988), SWAMPMOD (Konya et al., 1995), Wetlands Dynamic Water Budget Model (Walton et al., 1996), Soil Water Balance Model (Bidlake and Boetcher, 1996), FLATWOODS (Sun et al., 1998), SWAT (Arnold et al., 1998), REMM (Altier et al., 2002) and PHYDO (Pyke, 2004). STELLA® iconographic modelling software has been effectively used to simulate hydrology and nutrient dynamics in wetland systems (Mitsch and Reeder, 1991; Martin and Reddy, 1997; Zhang and Mitsch, 2005).

This study employs STELLA® to simulate hydrologic performance and behavior of two alternative constructed wetland designs that are variations on an optimal concept selected after a lengthy design process (Strosnider 2005). This new hydrologic model will be described as it is used to predict and compare hydrologic performance of the two candidate constructed wetland designs. A unique feature of this simulation tool is the incorporation of both surface flow and subsurface flow wetland design components.

Materials and Methods

Site Description

The target retrofit site is located 34 miles south of Charleston, South Carolina, on Kiawah Island at 32° 37' 10" N, 80° 3' 40" W (Fig. 1). Kiawah is a barrier island that historically supported maritime forest (Combs 1975) prior to a current land use of residential development as a gated community with a significant area of managed turf (golf course). Soils on the study site were originally in the Crevasse-Dawhoo complex (USDA, 1971), but site modifications through intensive regrading and soil mixing occurred during development and pond construction.

Figure 1: Location of the study site (circled in red) with respect to South Carolina (bottom) and greater Kiawah Island (top) (from Bunker, 2004).

The watershed of pond K67 (Fig. 2), where the wetland will be constructed, had low soil organic matter (circa 1.4 % by mass), basic soil pH (8.3-8.6), low inorganic N availability (below 10 $\mu\text{g N gdw}^{-1}$), and denitrification rates (50-250 $\mu\text{mol N m}^{-2} \text{h}^{-1}$) within a commonly reported range (Drescher 2005). The pond receives loads of NO_3^- and NH_4^+ of approximately 11.6 and 5.5 kg y^{-1} via stormwater (calculated from Bunker 2004). Average annual rainfall for Southeastern Coastal Carolina is 124.3 ± 10.1 cm (NOAA, 2000).

Figure 2: Wetland watershed and proposed wetland area in relation to the golf course, residential areas and pond.

The 2.4 acre detention pond receives stormwater from a network of subterranean conduits (Strosnider, 2005). The constructed wetland will receive and manage runoff from 8.4 acres of that watershed of which 41% is frequently fertilized golf course turf. Highly managed residential property comprises the remainder of the wetland watershed (Strosnider, 2005).

Generally, dissolved N in pond K67 is in the highly eutrophic range and dominated by organic forms (Hayes et al., unpub. data; Brock, 2006). N enters the pond as NO_3^- and NH_4^+ (Bunker 2004). However, N can cycle as NH_4^+ and accumulate within coastal ponds because the lack of a shallow littoral zone limits the opportunity for the NH_4^+ to undergo the nitrification that is required before denitrification can occur. Inorganic N in the pond is highly variable; e.g. mean ($\pm$ SD) NH_4 and NO_3 concentrations were 4.6 ± 9.6 and 7.5 ± 10.05 μM , respectively, between 2002 and 2005 (Brock, 2006), and dissolved organic N typically > 10-fold higher than dissolved inorganic N (Hayes et al. unpub. data). Other pathways for N transformation can dominate when denitrification is limited. Hongbo and Aelion (2005) found that dissimilatory NO_3^- reduction to NH_4^+ and NO_3^- -stimulated mineralization can be major sources of NH_4^+ in ponds and marshes receiving urban and golf course runoff in nearby Hilton Head, SC.

The elevated N levels in the ponds on Kiawah Island are periodically associated with harmful algal blooms. For example, from September through November 2004, a *Microcystis aeruginosa* (Cyanophyceae) bloom was sustained at > 100,000 cells/ml (Brock, 2006). Microcystin concentrations were consistently > 1 ppb over this period, and ranged to > 10,000 ppb. For comparison, the World Health Organization threshold for safe drinking water is 1 ppb (Yamamura, 2004). The common occurrence of harmful algal blooms by cyanobacteria and other potentially toxic algae in SC coastal ponds has been documented and linked to high N loads (Lewitus and Holland, 2003; Lewitus et al. 2003, 2004).

Design Descriptions

One of the greatest challenges of this project was working within the constraints of the golf course landscape. The site of the proposed wetland adjacent to the pond was also adjacent to

a golf course fairway, which was supported by a subsurface irrigation system. The resulting surveyed area provided for the opportunity to test two design options: one for maximizing the wetland size for maximum stormwater retention (Option A), and one for minimizing the size and minimizing cost as well as area of impact (Option B). In general, the two designs differ mainly in surface area, width of the berm, and cost of installation. Both designs incorporate aspects of subsurface and surface-flow constructed wetlands for processing both nutrient-enriched groundwater and stormwater (Table 1).

Table 1: Design features incorporated and rationale for inclusion.

Major Design Feature	Reasoning
Sinuosity	To dissipate flow energy; aesthetics
Unlined	To encourage groundwater interaction
Littoral Shelf	To encourage nutrient processing; to provide habitat
Carbon (C) Charged Substrate	To enhance denitrification potential (local substrate C-poor)
Forms to Existing Landscape	To reduce earthwork costs; aesthetics;
100% Native Plantings	To provide improved habitat benefits
Vegetated Spillway	To reduce erosion potential; aesthetics
Permeable Berm	To enhance filtration (equivalent to a broad subsurface flow cell)

Each design consists of a shallow channel running south along the east side of the pond to a southern basin with a vegetated spillway running northeast into the pond (Fig. 3a and b). The proposed canal ranges from 1.8 to 4.3 m wide at its base. The entire base of the proposed stormwater wetland is flat and approximately 0.8 m above mean sea level (msl). The proposed berm between the wetland canal and the pond will be built up to a height of just over 1.5 m above msl. The berm substrate will be augmented for denitrification with wood chips following findings by Drescher and Brown (2006) that denitrification rates increase in on-site soils with wood fiber and NO_3^- additions. Proposed slopes in the wetland are all less steep than 1:1, a slope designed to minimize erosion and suspended solids introduction to the wetland based on published recommendations (France, 2003).

The proposed wetland is unlined to allow for groundwater exchange. Three risers will bring stormwater to the surface and into the wetland from the subterranean stormwater drainage pipes (Fig. 3a and b). During a medium to small storm event, the proposed wetland will fill with stormwater without overflowing and slowly return to base height as seep empties the wetland through the hydraulically conductive berm. Larger storm events will cause the wetland to overflow via a vegetated spillway (Fig. 3a and b).

Figures 3a and 3b: Option A (left) and Option B (right) stormwater wetland designs. Area within the dashed line represents the area of the wetland base. Area within the solid line represents the maximum surface area of the wetland. Long dashed lines represent stormwater lines brought to the surface with risers.

Model Description

The hypothesis tested was that the smaller design option could be similar in performance to the larger design. It was expected that the smaller option would require less extensive earthwork for installation and would displace less of the fairway land area on the golf course. Another modification in the smaller design option was a narrower berm so that more water would seep to the pond over time due to the increased hydraulic connection with the pond (Table 2). The simulation tool presented below was used to test the performance of the two options by calculating the resulting stormwater management effectiveness.

Table 2: Differences in dimension and volume for the two compared designs

	Option A	Option B
Maximum Volume (gal)	59200	46500
Event Catch Capacity (gal)	33800	25900
Area of Wetland Base (m ²)	538	453
Maximum Surface Area (m ²)	1017	771
Average Littoral Shelf Width (m)	5.5	2.4
Average Seep Distance (m)	4.0	2.9
Total Earthwork Cut Volume (y ³)	1563	1103

The model created for this study was based on a water balance approach (Fig. 4, Eq. 1) and simulates daily hydrologic conditions for the two wetland design options, each of which is proposed to be bordered by uplands on one side and the pond on the other (Fig. 3a and 3b). Large wetlands should not be modeled with this tool and would be better simulated with gradually-varied flow models or multi-segregated finite difference models. The model is intended to be easily parameterized to determine the hydrologic regime of a small lacustrine, palustrine, or riparian constructed wetland.

$$\frac{dV}{dt} = R + D_r - ET - O \pm S \quad (1)$$

Where: $\frac{dV}{dt}$ = Change in wetland water storage (m³/d)

R = Surface runoff (m³/d)

D_r = Direct rainfall on wetland area (m³/d)

ET = Evapotranspiration (m³/d)

O = Spillway Overflow (m³/d)

S = Seep (m³/d)

Figure 4. Pools and fluxes used in the STELLA® model for simulating hydrologic performance and behavior in the constructed wetland. Arrows represent accounted flows.

Runoff was calculated with the rational method (Strom and Nathan, 1985). ArcGIS® 9.0 software was used to determine contributing area attributes. Runoff coefficients were taken from literature (Strom and Nathan, 1985). Rainfall data was gathered from two weather stations on Kiawah Island. The bulk of the weather data used was from a National Oceanic and Atmospheric Administration (NOAA) Agro-Meteorological weather station situated approximately 50 m East of the North end of the proposed constructed wetland, and where lacking, data were obtained from the Kiawah Island Community Association Maintenance weather station located 4.97 km from the center of the proposed constructed wetland.

All areas for the rational method were delineated by using local LIDAR topography maps provided by the Kiawah Island Community Association, aerial photography provided by the South Carolina Department of Natural Resources, and ground-truthing within the watershed by a survey crew. The surface runoff (R) value included both direct overland runoff and piped stormwater that would enter the wetland. An estimated 92% of the wetland watershed's R will arrive via piped stormwater. However, because the model was run on a relatively long (24 hr) timestep, the piped stormwater and overland runoff were modeled to flow into the wetland simultaneously during each model iteration.

Direct rainfall (D_r) on the wetland was estimated by multiplying the daily wetland water surface area by the rainfall intensity. The daily wetland water surface area was a function of the daily wetland water volume. During simulated drier conditions, the unsaturated area within the wetland was added to the terrestrial part of the watershed for estimation of runoff area and was assigned the runoff coefficient for a grassed area as presented by Strom and Nathan (1985).

The Dupuit approximation for unconfined aquifer flow (Wang and Anderson, 1982) was used to determine daily seep (S) into and out of the side of the wetland bordering the neighboring water body. Mandatory inputs include seep distance, stages of both the wetland and the pond, seep face length and hydraulic conductivity. A linear equation was created to calculate seep distance given wetland stage inputs (Eq. 2). Pond stage, which is fixed by a weir, was set as a constant. The wetland stage was calculated as a function of wetland volume. The seep face length was determined directly from dimensions on design blueprints. The upper hydraulic conductivity bound of the local soils, 12.2 m/d, was used because Kiawah has been drained and developed since the soil survey (USDA, 1971).

$$L_s = L_{\min H} + \frac{L_{\max H} - L_{\min H}}{h_{w \max}} (h_w) \quad (2)$$

Where: L_s = Seep length through the spillway (m)

h_w = Daily wetland water stage (m)

$h_{w\max}$ = Wetland water depth when at maximum capacity (m)

$L_{\max H}$ = Seep length at full wetland stage (m)

$L_{\min H}$ = Seep length at minimum wetland stage (m)

ET was estimated as potential ET (PET in $m^3 d^{-1}$) calculated with the Penman method as presented in Kadlec and Knight (1996). The wetland water surface area, a function of wetland stage, was used as the surface available for ET . Daily spillway overflow was computed with an “if” statement that exported water over the maximum capacity of the wetland. Maximum wetland capacity (V_o in m^3) was estimated with Eq. 3.

$$V_o = \frac{1}{2}(A_{\max H} + A_{\min H})h_{w\max}n \quad (3)$$

Where: n = wetland porosity

$A_{\min H}$ = Area of the wetland base (m^2)

$A_{\max H}$ = Wetland water surface area when full (m^2)

$h_{w\max}$ = Wetland water depth when completely full (m)

Model Assumptions

Specific assumptions that were made for the hydrologic simulation include: (1) the hydraulic conductivity of the berm to be uniform and $12.2 m d^{-1}$ (USDA, 1971); (2) wetland porosity (n) was set at the minimum of the recommended range provided by Reed et al.'s (1995) as $0.675 cm^3 cm^{-3}$, although Kadlec and Knight (1996) argue that n is usually greater than 0.95, because the shallow wetland in ample sunlight should end up as a densely foliated ecosystem; (3) heat conduction to ground was omitted because data were lacking and, when calculated with available data and parameter estimates from Kadlec and Knight (1996), it was found to be inconsequential to ET ; (4) groundwater flow on the upland side of the wetland would be negligible because the wetland should raise the local water table to reduce an already minimal hydraulic gradient (Bunker, 2004), and (5) vertical groundwater flow was set to zero because the relatively static local water table is very close to the surface (USDA, 1971).

Nitrogen Processing

Outside of the hydrologic model, an estimate of the potential for N processing Option B was calculated sequentially using NH_4^+ and NO_3^- processing constants (k) of 18 and $35 m y^{-1}$ respectively, background concentrations of zero and the first order areal model from Kadlec and Knight (1996), average daily residence time from the hydrologic model, a weighted average based on stormwater grate watershed areas from Bunker (2004), and the average NH_4^+ and NO_3^- concentrations calculated from Bunker's data.

Results and Discussion

Estimated Stormwater Quantity Management

The volumetric capabilities of the two design concept options for managing stormwater quantity are presented in Fig. 5 in terms of the overall water balance and based on simulation results for over two years (approximately 29 months) of input data from September 11, 2002 to February 21, 2005. In order to estimate the stormwater management capability of the two options, the percentage of each water balance component was calculated based on total stormwater flow. For Option A, the simulated results indicate that of the 21,990 m³ (5.8 million gallons) of stormwater generated from the drainage area, approximately 7,519 m³ (2 million gallons) or 34.2% would pass through the berm, approximately 13,893 m³ (3.7 million gallons) or 63.2% would pass over the spillway, and approximately 2,983 m³ (788,000 gallons) or 13.6% would be lost via *ET*. For Option B, the simulated results indicate that of the 22,074 m³ (5.8 million gallons) of stormwater generated from the drainage area, approximately 7,985 m³ (2.1 million gallons) or 36.2% would pass through the berm, approximately 13,838 m³ (3.7 million gallons) or 62.7% would pass over the spillway, and approximately 2,274 m³ (600,000 gallons) or 10.3% would be lost via *ET*. The difference in the estimated stormwater inputs between Option A and Option B is due to the latter option having a larger drainage land area, which would produce a slightly greater stormwater input into the smaller wetland.

Figure 5. Comparisons of simulated total flows for the larger Option A and smaller Option B constructed wetland design.

The quantities of stormwater management per water balance loss components in each of the above calculations result in an overall water budget of greater than 100%. Therefore, for full consideration of water balance inputs versus outputs, direct rainfall and stormwater

contributions were considered. For Option A, of the water balance inputs (stormwater and direct rainfall) of 24,141 m³ (5.8 million gallons), 31.1% would pass through the berm, approximately 57.5% would pass over the spillway, and approximately 12.4% would be lost via *ET*. For Option B, of the water balance inputs (stormwater and direct rainfall) of 23,705 m³ (6.3 million gallons), approximately 33.7% would pass through the berm, approximately 58.4% would pass over the spillway, and approximately 9.6% would be lost via *ET*. From an overall stormwater management effectiveness standpoint, wetland water quantity management effectiveness was based on the total amount of water either leaving the system via berm seep or *ET* compared to the total input into the system (stormwater and direct rainfall), while greater overflow compared to inputs resulted in a reduction of estimated effectiveness. The overall wetland water quantity management effectiveness, based on 29 months of simulation data, was 43.5% and 43.3% for Options A and B, respectively, suggesting nearly identical effectiveness.

Comparison of Estimated Wetland Residence Time

Because water residence time is the most important predictor of constructed wetland performance (Reed et al., 1995; Kadlec and Knight, 1996), residence time was used to evaluate performance of the two designs. Daily residence time was calculated using estimated water storage volume based on wetland water stage (m) and the associated wetland surface area at that stage (m²) as well as the daily average inflow (stormwater in m³/d) and outflow (overflow in m³/d). Monthly average residence times were subsequently calculated based on simulation results (Fig. 6).

Figure 6. Average monthly residence time and seep over the full simulation period.

The monthly average residence times ranged from 11 to 48 days for Option A and 10 to 53 days for Option B, resulting in average simulated monthly residence times of approximately 22 days and 20 days for the larger Option A and smaller Option B wetland designs, respectively. Both

options should perform well because these residence times are on the higher end of recommended design criteria for adequate wetland treatment system performance (Kadlec and Knight, 1996). The slightly shorter simulated residence time for Option B is attributed to the thinner berm and resulting greater seep. The simulated residence times of both designs were longer in the winter due to lower *ET* and rainfall during that season.

Comparison of Estimated Wetland Performance

Based on simulation results, Option B performed similar to the larger design, primarily due to the enhanced hydraulic connection with the pond. The predicted increase in berm seepage (6.2%) for Option B suggests that the thinner berm is preferable because effluent seeping through the berm should have a high chance of N attenuation due to the C-rich substrate within. Predicted overflow is similar for the two designs, which suggests that average stormwater storage capacity was not reduced in the smaller design. Although the Option A design can receive larger events, the Option B design can drain faster to be ready for the next event. However, comparisons of total predicted volumetric flows revealed the designs were similar in function, despite Option B being 22% smaller than Option A.

Option B was predicted to both fill up and empty more quickly than the larger option (Fig. 7). However, because of its greater hydraulic connection to the pond by way of the narrower berm, Option B wetland design was predicted to deviate less than the larger design from the 0.21 m pond stage relative to the base of the wetland. The small decrease in the predicted average stage from 0.28 m for the larger Option A design to 0.27 m for the smaller Option B design is not expected to influence macrophytes because the water depth is still within the optimum depth of 0.1 - 0.3 m recommended for herbaceous macrophytes (Mitsch and Gosselink, 2000).

Figure 7: Comparison of stormwater input and simulated wetland stage for the two constructed wetland designs over a short part of the simulation period. The shortened time scale is used here to illustrate differences in the simulated stage responses to storm events. Pond stage, which is controlled by a static weir, is represented by the black line.

Nitrogen Processing Estimation

The option B design has estimated potential NH_4^+ and NO_3^- removal rates of 0.6 and 1.3 mg L^{-1} , resulting in areal removal rates of 0.17 and 0.44 $\text{kg ha}^{-1} \text{d}^{-1}$, representing 74 and 92% reductions from influent concentrations respectively. If realized, the design's N processing efficiency would be greater than the average constructed surface-flow, constructed subsurface-flow and natural wetlands documented in the North American Treatment System Database by Knight et al. (1993). The high processing efficiency predicted is primarily a function of the relatively high residence time inherent in the design. As previously discussed, average simulated residence times for the two designs evaluated in this study suggest both options should perform well. Also, although NO_3^- and NH_4^+ processing rates decrease as temperatures decline (Kadlec and Knight, 1996; Lee et al., 1999; Werker et al., 2002), the greater predicted winter residence time may to some extent counteract the lower activity rate for soil microbes during that season.

Conclusions

Simulations suggest there will be little difference in performance if the smaller wetland design option is selected. Although there is a relatively large reduction in wetland volume (22%), the thinner berm, decreased from 4.0 m in Option A to 2.9 m in Option B, should result in a greater amount of water seeping into the pond, no significant change in overflow volumes, and only a slight decrease in residence time. The decrease in residence time should be functionally compensated by the increase in seep through the berm that should allow biogeochemical transformation of N compounds. Therefore, performance of Option B should be similar to that of Option A while possibly presenting less construction cost because of the near 30% reduction in earthwork volume. The relatively high N processing potential of Option B suggests that N loading to downstream detention ponds and estuaries can be significantly reduced by this BMP. The modelled concept may present a reliable alternative BMP for future holistic stormwater management in existing or planned stormwater ponds. As ponds have been typically designed to manage water *quantity*, the model presented may provide data for developing a pond design or retrofit wetland option that allows for improving the ability of existing or future stormwater ponds in coastal South Carolina to manage water *quality*.

The hydrologic model presented in this paper was designed to be expanded upon. C and N modules, including macrophyte nutrient uptake, growth and senescence as well as daily denitrification and nitrification, are currently being refined and added to the model.

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