Evaluating Impacts of Master Planned Communities’ Fertilization Practices on Water Quality Using the Watershed Assessment Model (WAM): The Restoration Project Case Study

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Accurately anticipating the impacts of urbanization has clear environmental and economic advantages. The growing number of impaired Florida waters and associated Total Maximum Daily Loads (TMDLs) suggests that a more reliable alternative to the current “rebuttable presumption of compliance” is needed to evaluate water quality impacts. This paper considers the use of dynamic watershed simulation models for evaluating water quality impacts associated with the design and fertilization practices of master planned communities. Specifically, this study uses the Watershed Assessment Model (WAM) to simulate nutrient loading associated with two distinct plans (extensive and compact) proposed for the Restoration Development of Regional Impact in Edgewater, FL. Preliminary simulations indicate that N and P loadings can be positively and significantly lowered (by 47% and 31%, respectively, in this case study) as a direct result of reduced inputs and the preservation of open space, attained with the reduction of development footprint and managed landscapes.

The U.S. Environmental Protection Agency (EPA) and the Florida Department of Environmental Protection (FDEP) recognize N and P loadings as a leading cause of degradation and impairment of state waters [Florida Statutes s. 62-302.300 (13); Kaufman et al., 2010]. One in nine water body segments in the state were impaired by nutrients in 2010, with financial implications on the order of billions of dollars (FDEP Division of Environmental Assessment and Restoration, 2010). The environmental consequences of nutrient runoff from anthropogenic sources are well documented (Conley et al., 2009; FDEP, 2010b; USEPA, 2010a), and projected climate change is likely to intensify algal blooms resulting from nutrient pollution (Moss et al., 2011).

Florida’s rapid land development has directly resulted in the extensive destruction of wetlands and loss of associated ecosystem services (FDEP, 2010b; Kinser et al., 2006; McCurk and Fischl-Presley, 2002). Master planned communities (MPCs) represent a significant share of such development, Very large MPCs are designated as Developments of Regional Impact (DRIs). Specifically, Florida considers MPCs to be DRIs if they are likely to have substantial effect on more than one county for exceeding a certain threshold, such as 600-bed hospitals, 400,000 ft² of retail area, or 250 dwelling units and up, tiered according to county population (Florida Statutes s. 380.06). DRIs alone accounted for 38% of 1.5 million permits for residential units issued in Florida by local jurisdictions from 2001 through 2010 (US Census Bureau, 2011). MPCs are capital intensive enterprises that rely on practices demonstrated to ensure a safe and sufficient return on investment. To ensure stormwater permits, many MPCs rely on dredge and fill and contour mapped grading that effectively clears the land, disrupting and compacting soil profiles in the finished graded site. MPCs also establish architectural and landscape standards to ensure the look and feel of their communities. Conventional Florida MPCs use turfgrass extensively in residential landscapes and use community Covenants, Conditions and Restrictions (CC&Rs) to require homeowners to maintain them with regular fertilization and irrigation. These landscape practices in combination with the compacted and altered soil profiles can have a detrimental impact on soil infiltration and water quality (Gregory et al., 2006; Hagan et al., 2010). Small parcels of private and common landscaped areas, mostly centrally managed, are a significant share of the land uses (LUs) in a MPC. The combination of current site development methods and landscape maintenance requirements perpetuates an intensive deployment of nutrients, often times leached or carried away by excess irrigation water.

Pollution issues were not solved with the adoption in 1999 of Total Maximum Daily Loads (TMDLs) (Florida Statutes s. 403.067) associated with the Federal Clean Water Act of 1972 (33 U.S.C. §1251 et seq.), leading to the adoption of the Impaired Water Rule (ch. 62-303 Florida Administrative Code, Florida Senate Committee on Natural Resources, 2003; Norgart, 2004). Studies found “a high degree of variability in the pollutant removal effectiveness of commonly used [stormwater] systems” and showed the limitations of uniform statewide requirements. Following these findings, FDEP funded research to assess the efficiency of pollut-
The research method consisted of two distinct steps: (i) parameterization and evaluation of two distinct community development master plans with the same basic level of fertilization using a simulation model; and (ii) simulation of the application of two alternative fertilization treatments. The more compact development plan (B) was used to test the influence of two managed landscape parameters (with all other variables kept the same), namely: the amount of fertilizer input and changing the area of low-maintenance turfgrass and plants, which will result in a further reduction in fertilizer and water inputs.

The Watershed Assessment Model (WAM) was the simulation tool of choice for this study. It is a dynamic Geographic Information Systems (GIS)-based peer reviewed model (Graham et al., 2009), developed for Florida field conditions and listed by EPA as capable of simulating basin hydrology and nutrient dynamics of watersheds (USEPA Ecosystems Research Division, 2011). WAM works as an extension to the ArcMap software application (ESRI, 2009) and it integrates site specific natural features, LUs, soils, and climate with complex biochemical processes, nutrient cycles, surface and groundwater hydrology, and stream, reservoir and control structure hydraulics. Three specialized field models generate and discharge daily nutrient loads, flows and concentrations that attest the system’s response to a certain configuration or “scenario.” Originally developed to simulate the effect of LU conversions of natural landscapes and crop fields in the Kissimmee River Basin and the Everglades, WAM and its sub-models GLEAMS (Knisel and Davis, 1999; Leonard et al., 1987), EAAMOD (Bottcher et al., 1998; Soil and Water Engineering Technology, Inc., 2000), and Special Case (Soil and Water Engineering Technology, Inc., 2012) have been successfully calibrated and validated in more than 40 major public and private projects with scales ranging from small acreages to river basins. Applications include the parameterization of urban features; evaluation of a wide range of agricultural and mining operations; development of TMDLs and regulatory strategies; and pre-development assessment of projects such as a municipal stormwater master plan, springsheds, and watershed scale water resource and abatement strategies.

The “Restoration” project is a 5,187±-acre (2,096 ha) DRI in the City of Edgewater adjacent to Interstate 95 in eastern Volusia County, FL (Canin Associates, 2010a). Two distinct master plans featuring the same number of dwelling units (8,500) and about the same acreage of non-residential uses (320 acres on average) were conceived for the site, providing a unique opportunity to evaluate contrasting LU configurations. The first conceptual plan, proposed in 2006 (henceforth “Plan A,” Fig. 1) was withdrawn after experiencing resistance from various groups involved in the permitting process. The master plan approved in 2009 (henceforth “Plan B,” Fig. 2) features a compact design that, along with higher residential density and building intensity (70% more office and retail space), reduces impervious surfaces by 37%, roadways by 47%, and the length of the development perimeter to conserved lands (“edge effect”) by 75%. Plan B also increases preservation lands by 35% when compared with Plan A (Canin Associates, 2010b).

Mass-grading and stormwater management plans have been approved by the SJRWMD (Donald W. McIntosh Associates, Inc., 2009). The existing terrain is quite flat, with a low-high point range of no more than 3 m (10 ft) and featuring some depressional areas. Soils vary in texture from clayey to sandy, supporting both upland and wetland-type vegetation. Most wetland soils are highly organic.

Plans A and B constitute the two “base scenarios.” For each scenario a network composed of connecting reaches, control structures, and reservoirs was defined to represent engineered drainage plans (Plan B) or a schematic drainage plan analogous to alternative B (Plan A). Plan A and B base scenarios were kept as similar as possible except for LU definition and spatial distribution. Plans A and B base configurations feature 327.3 and 133.0 ha of managed landscapes, respectively, 55.5% of which on average are covered by turfgrass. A “moderate” yearly rate of N fertilizer for central Florida (3 lb N/1,000 ft² yr⁻¹ or 146.5 kg N ha⁻¹ yr⁻¹) is applied to ornamental plants and bahiagrass (FDEP, 2008; UF/IFAS Extension and FDEP, 2009) in both plans, as a 16:2:K (N:P:O₃:K₂O) fertilizer ratio. Turfgrass clippings were returned to the soil as recommended.
Two variation scenarios to Plan B were defined to simulate BMPs that would reduce the input of fertilizers and consequently lessen the environmental burden to the watersheds. In variation B-1 (reduced fertilizer) the “basic” yearly rate of N fertilization recommended by the UF/IFAS Florida Yards and Neighborhoods program (2 lb 1,000 ft²·yr⁻¹ or 96.7 kg·ha⁻¹·yr⁻¹) is applied to 73.6 ha of lawns, while no fertilizer is applied to ornamental plants. This variation assumes that 100% of plants would be “Florida-Friendly” (drought tolerant and adapted to local conditions), requiring minimal to no fertilization.
A second variation, B-2 (reduced fertilizer and turfgrass), differs from the first in that the share of lawns in managed landscapes is reduced on average 38.5% (30% to 40% depending on the land use). This variation brings the mean fertilization N rate down from 54 to 31 kg·ha⁻¹·yr⁻¹, and would be a configuration very similar to that expected to be created by the CC&Rs based on the development order issued by the City of Edgewater, except that the irrigation treatment was kept constant throughout the scenarios to avoid changing two variables at once. In all scenarios P was applied at a rate of 2% P₂O₅ equivalent (or 0.872% as elemental P) of gross fertilizer weight, consistent with the 16:2:K formulation.

The irrigation setting for all scenarios was a fixed depth of 148 cm (58 inches) yr⁻¹, corresponding to an application of 13 mm (0.5 inches) wk⁻¹ during the winter and 38 mm (1.5 inch) wk⁻¹ during the summer (FDEP, 2008). The same irrigation rate was applied to 100% of all maintained landscapes. However, accounting for natural vegetation and less intense maintenance of public areas, only 75% of landscapes within rights of way and parks and recreation LUs were assumed to be managed.

Results and Discussion

The preliminary N results from the two base scenarios along with the two treatment variations are displayed in Fig. 3. Plan B had total N loads 47% lower than Plan A. Nitrogen loads with sources within the development site (the sum of fertilizer N with urban and native soil contributions and atmospheric N deposition over open water, henceforth “gross inputs”) are shown above the horizontal axis while site outputs via surface waters are shown below the axis (in dark gray). Because of the relatively fixed amount of nutrients released by urban soils and by native and open water LUs, output totals do not diminish as steeply as inputs do, but reductions are nonetheless significant. Taking Plan B as the benchmark, gross inputs 40% smaller correspond with a decrease of 32% in output for variation B-1. However, N fertilizer inputs change from 75% greater than outputs (175%) to only 5% greater, i.e., only a small fraction of the output. For variation B-2, 51% less gross inputs translate into an output diminished by 41%. This time, N fertilizer inputs represent only a fraction (38%) of the total output.

A more drastic trend was observed regarding P (Fig. 4). Essentially all fertilizer P applied to landscapes in the model is consumed or stays within the source cell, because site output is virtually constant. A reduction in fertilizer P of 63% (B-1) or even 79% (B-2) yielded a zero effect in output. This result was not surprising given the relative immobility of P in soil compared with N. The simulation period may not have been long enough to account for long-term movement of P and N once soil saturation is reached after continued annual applications. But fertilizer P input, formerly 25% greater than the output (125%) became a 46% (B-1) and eventually a 27% fraction in B-2. Plan B produced a total P loading rate and concentration higher than Plan A on a unit-surface basis, but still performed 31% better because its footprint is about 42% smaller than the alternative.

This example simulation shows not only that natural nutrient sources and cycles contribute to availability and movement of...
Fig. 4. Phosphorus site totals: fertilizer input, soil and atmospheric contributions, and attenuated output (kg yr\(^{-1}\)). Similar to N, though in quantities about 14 times smaller, soil and rainfall deposition contributions to P loads are fixed and appear to contribute to the diminishing effect of fertilization.

N and P within urban landscapes, but that taking that into account and minimizing fertilizer inputs on managed landscapes in MPCs can contribute to reductions in nutrient loading within impaired watersheds. The continued annual applications of both nutrients at a rate beyond the capacity of biomass and soils to absorb them would be expected to cause N and P loads, not immediately leached or carried away by runoff, to first accumulate and eventually move out of the soil and into ground and surface waters. Denitrification is unlikely to account for the total amount of excess N applied each year.

### Conclusion

The prospect of a reduction of nutrient loads achieved by Plan B in contrast with Plan A (47% for total N and 31%, total P) is significant. The simulation results featuring reduced fertilization and a reduced share of turfgrass in this case study suggest that design and management practices in MPCs such as the adoption of conservation measures like Florida-friendly landscaping practices may contribute to reduced nutrient loads. Simulation models such as WAM provide an opportunity to evaluate relative impacts of proposed development designs before long-term infrastructure is put into place.

It is early for definitive conclusions, as this is still a work in progress. Computerized simulations are complex and labor intensive, but this experiment has demonstrated the need for a more dynamic and long-term assessment of the performance of major urbanization projects and management practices, as well as the

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