City of Stuart

Watershed Performance Evaluation

Relationships Between Nutrient Loading Estimates and Total Maximum Daily Loads

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July, 2008

Introduction

The St. Lucie Estuary and most of its major tributaries are listed by the Environmental Protection Agency (EPA) and Florida Department of Environmental Protection (FDEP) as "impaired waters". These impairments are most frequently due to low dissolved oxygen, as relatively high chemical and biological oxygen demand frequently reduces oxygen levels below 5 parts per million (ppm). High Chloropyl A is associated with high phytoplankton levels, which create diurnal boom (during the day) and bust (overcast or night) levels in dissolved oxygen concentrations. These impairments typically indicate nutrient levels exceed those found in healthy estuarine waters.

FDEP has been working for nearly five years to establish nutrient target levels for impaired waters in the St. Lucie Estuary and its tributaries. This process first requires data to prove impairments exist, analysis to determine most probable causes, determination of target levels for the constituents that are causing the impairment, and then creation of Basin Management Action Plans or "BMAPS" for watersheds surrounding impaired waters. Finally, landowners and agencies with point and non-point source water management responsibilities within BMAP watersheds will be required to identify and reduce sources of excess pollutants.

The primary causes of impaired waters in the St. Lucie Estuary and its tributaries have been determined to be the nutrients nitrogen and phosphorus. After target concentrations of these nutrients are established, each tributary will be assigned Total Maximum Daily Loads (TMDL's) of nutrients that, if not exceeded, are assumed to enable impaired waters to recover ecological health and be removed from the impaired waters list.

At present, the draft TMDL targets, measured at the Roosevelt Bridge in the St. Lucie Estuary, are 0.74 mg/L Total Nitrogen and 0.081 mg/L Total Phosphorus (FDEP June 3, 2008). Tidal exchange, rainfall and groundwater dilution within the St. Lucie Estuary may result in some tributary concentration targets being slightly higher than these concentrations, although that remains to be determined.

The City of Stuart will soon be required to comply with the adopted TMDL's. Anticipating this process, the City commissioned an independent study of its watersheds by Berryman and Henigar, titled Surface Water Quality Assessment for the City of Stuart, dated March 2005. This study predicted significant nutrient and load reductions would be required for the City to comply with anticipated TMDL's.

Since that time, the City has continued construction of its comprehensive Watershed Improvement Program. Before the end of 2008, the last major watershed retrofit project will be completed (for Poppleton Creek), and the last five direct-piped stormwater outfalls to the St. Lucie Estuary will be retrofit with baffle boxes.

The City's Stormwater Utility collects fees from every property owner in the City based on ownership acreage and impervious surface coverage, with a reduction factor if the property is served by a modern, permitted stormwater management system that includes water quality treatment. These fees support cleaning baffle boxes, sweeping streets, and maintaining the watershed projects.

The City obtained a National Pollutant Discharge Elimination System (NPDES) permit in 2003. It will be due for renewal in 2008. All indications are that the voluntary reductions in nutrient loading called for in the 2003 NPDES permit will become mandatory when TMDL's are adopted, thereby limiting allowable nutrient concentrations in stormwater originating within the City limits.

The present investigations rely on extensive water quality data collected by South Florida Water Management District (SFWMD) since 2001 to evaluate performance of the City's Watershed Improvement Program and compare actual performance with theoretical predictions of the 2005 Berryman and Henigar study, as well more recent nutrient loading predictions by FDEP and SFMWD.

Stormwater Quality: Theory and Reality

The modern history of stormwater quality research is relatively short. Comprehensive studies are very expensive, requiring extensive water quality sampling for multiple constituents up and downstream in watersheds over a variety of rainfall events. Every watershed is unique in terms of size, impervious coverage, soils, topography, and other important factors. For all these reasons, data collected from one, or even many watersheds, may not be accurately predictive with regard to all watersheds.

M.P. Wanielista published then-definitive stormwater quality studies in Stormwater Management: Quality and Quantity in 1978. H. H. Harper has followed with a number of Florida studies, however, like Wanielista's, most are based on Central Florida research. These and other studies have been used to estimate pollutant loading rates for stormwater runoff. As studies have become more sophisticated, they have increasingly attempted to differentiate pollutant loading by different land uses, in order to better predict the behavior of watersheds.

The most recent study directly applicable to the St. Lucie River watershed of which we are aware is Water Quality Characteristics of Storm Water from Major Land Uses in South Florida, (Graves, Wan and Fike, 2004). This study reports concentrations of various pollutants in rainfall runoff for specific land uses within the St. Lucie watershed, but does not provide runoff rates or acreages of tributary land uses that would enable calculations of annual pollutant loading by land use type.

There are relatively few comprehensive studies of how various stormwater control techniques affect pollutant removal once rainfall runoff has collected pollutants from the land. At most, the best studies taken in total provide general guidance as to how various land uses are associated with pollutants that end up in rainfall runoff, and how much downstream facilities such as lakes, wetlands, retention and detention ponds, weirs, baffle boxes, etc. can reduce that pollutant load.

In order to make widest use of the data available, the most common approach to estimating pollution loading in a watershed is to inventory the various land uses within it, select a literature-based estimate of per-acre pollution loading for each land use, inventory the acres of each land use in the watershed, and use a spreadsheet or computer model to calculate annual pollutant loading for that watershed. By estimating how much rainfall runoff occurs from a watershed, the annual load can be reduced to pollutant concentrations, generally expressed in milligrams per liter (mg/L) or equivalent parts per million (ppm).

If there are stormwater quality management facilities within the watershed, additional literature-based estimates of pollutant removal efficiency can be applied to each such facility and an estimate of net pollution leaving the watershed can be calculated.

When the land areas involved in such studies are large, and the monitoring data at the downstream end comprehensive, pollution loading estimates can be adjusted (the model "calibrated") so that predicted loading and measured pollution concentrations can be reasonably well matched. However, this method also averages high nutrient load "hot spots" with low load "cool spots", and calibrated models with multiple land use types are subject to considerable interpretation as to how much each land use type is influencing the overall behavior of the watershed with respect to pollutant loading.

This process was used by the Indian River Lagoon Restoration Feasibility Study to evaluate the major tributary basins to the St. Lucie Estuary (C-23, C-24, C-44, Winding North Fork, Winding South Fork, and combination Tidal Basins) during creation of the IRL Plan. This Plan proposes

nearly 20,000 acres of water storage and treatment areas within the major canal basins, in part to improve water quality, and in part to improve the timing and delivery of freshwater to the Estuary in order to maintain salinity within desirable ranges for estuarine habitats.

The IRL Plan is not a complete solution to water quality improvements necessary to reach the calculated target concentrations within the Estuary itself. It was assumed that additional Best Management Practices (BMP's) to reduce nutrient loads would be implemented by landowners and local governments. The IRL Plan further assumed Lake Okeechobee would not discharge into the Estuary, an assumption that has not proven plausible to date and that may render all other efforts to improve estuarine health moot if those discharges continue.

The process used by Berryman & Henigar (B&H) to estimate the extent to which TMDL targets would be met by City of Stuart is similar to that used in the IRL Plan, except that individual City watershed water quality data was not used to calibrate their model. B&H used literature values for pollutant loading by land use, literature values for pollutant removal efficiencies for water quality control improvements identified in the City's Watershed Improvement Program, calculated net pollution loads, and then compared these calculated loads to the IRL Plan targets in terms of annual nutrient loads in tons/year.

It was assumed that the overall IRL Plan targets for net annual pollution reduction would be pro-rated over the City's land area, as none of the IRL Plan projects to improve stormwater quality were planned within the City limits. First, assuming the Watershed Projects and Stormwater Utility maintenance programs did not exist, The B&H modeling estimated total nitrogen (TN) loading from the City to the St. Lucie Estuary at 27.743 metric tons/hear and total phosphorus (TP) loading 4.378 metric tons/year.

After completion of the City's Watershed Improvement Program, the B&H modeling estimates reductions in TN to 23.678 tons/hear and TP to 3.145 tons/year. Considering the City's land area is 4,227 acres, these performance estimates indicate that after implementation of all planned Watershed Improvements, 5.6 kg/acre/year TN and 0.744 kg/acre/year TP would be drained from within City limits to the Estuary in rainfall runoff.

These estimates were then compared to IRL Plan nutrient target reductions, with the conclusion that less than ½ of the nutrient loading reductions required by the prospective TMDL targets would be met by the City's proposed projects, and significant additional nutrient controls would be required within the City in order to meet TMDL targets.

More recently, FDEP and SFMWD, in conjunction with TMDL modeling data, have released draft chapters of a St. Lucie River Watershed Protection Plan that address nutrient loading by land use with both predicted and measured nutrient concentrations from various watersheds. One of these, prepared by Soil and Water Engineering Technology, Inc and dated May 8, 2008, provides a variety of nutrient loading, concentration and runoff data for the St. Lucie River watershed.

These data indicate the South Tidal St. Lucie Basin totals 49,962 acres, with computer-predicted loads of 138 metric tons of TN/year and 27 metric tons of TP/year. Measured concentrations and rainfall runoff assumptions calibrate these estimates to 91 tons TN/year and 21 tons TP/year.

Using B&H estimates compared to the latest measured concentrations from agency studies (Soil and Water Engineering Technology, Inc), and comparing the acreage of the City to that of the South Tidal Basin, the City would be predicted to produce 26% of the TN loading within the St. Lucie Tidal Basin and 15% of the TP loading, although the City would comprise only 8.5% of the land area in the South Tidal Basin. Land uses within the South Tidal St. Lucie Basin are 17,883 acres (35.8%) urban land, 28,079 acres (56.2%) agriculture, and 14,021 acres (28.1%) native land or water.

Graves, Wan and Fike (2004) present a thorough data set comparing various land use types within the St. Lucie Basin and report that urban land uses typically generate lower nutrient concentrations in rainfall runoff than any of the other land uses studied except for native wetlands.

We conclude that computer models using literature-based loading rates by land use provide a decent “rule of thumb” tool for estimating nutrient loads when basins have relatively consistent land uses and downstream calibration data such as concentrations and basin flows are available to adjust the loading rates. However, absent calibration, these nutrient loading data are not accurate enough to plan major public expenditures to further reduce nutrient loads for the City of Stuart, particularly if alternative data sources and calculation methods that offer greater accuracy are available for comparison purposes. Fortunately, such data are available.

SFWMD Water Quality Data

Boyd Gunsalus, Lead Environmental Scientist for SFWMD, has collected comprehensive water quality data from 48 different tributaries to the tidal St. Lucie River. Some of these have been monitored continuously since 2001, some discontinued and moved to other locations. Data

were initially collected biweekly, then twice monthly. 14 day antecedent rainfall is also part of the data set, as are some stream flow records that are collected but not yet available.

Partial or full data sets are available at the outfall points of four City of Stuart Watershed Improvement Projects. Data were collected at the Haney and Poppleton Creek Watersheds from 2001-2003. Data were collected at the Frazier and Airport Ditch Watershed projects from 2001 to present. These latter two are the most complete sets of data for any watershed in the City, and both reflect water quality since watershed improvement projects were constructed.

City of Stuart Watershed Improvement Projects

Frazier Creek

The first modern City watershed improvement project began in the early 1990's in the upper Frazier Creek basin, as part of an overall infrastructure improvement project in the East Stuart neighborhood. Existing lakes providing wet and dry retention were expanded and improved, and new storm sewers and control structures installed. This was followed in the mid 1990's by exotic removal, muck sediment removal, and construction of a sediment trap downstream in the watershed's main outfall ditch to tidal Frazier Creek. A "v" notched weir was constructed to stage groundwater up, capture sediments behind the outfall to tide, and to provide low flows via gradual groundwater drawdown to moderate salinity in Frazier Creek.

In 2000 the City purchased the former Stuart Trailer Town, a post WWII RV park, converted to a 1.4 acre retention/detention lake controlled by the existing weir. In 2003 the City removed exotics, installed baffle boxes at direct outfalls and dredged accumulated muck sediment deposits from tidal Frazier Creek between Colorado Avenue, approximately 600 feet downstream of the weir, and the mouth of Frazier Creek at Shepards' Park.

The Frazier Creek watershed is approximately 503 acres in area, comprising 11.9% of the City land area. It consists of small lot residential, commercial, industrial and institutional land uses, most developed long before modern stormwater management techniques were required by regulation. There are very few septic tanks in use in the Frazier Creek Basin.

SFWMD monitored water quality biweekly just upstream of the existing weir outfall point to tidal Frazier Creek from November 2001 through April 2008. For TN, median concentration is 0.63 mg/L, mean is 0.69 mg/L, and geometric mean is 0.66 mg/L. For TP, median concentration is 0.073 mg/L, mean is 0.085 mg/L, and geometric mean is 0.079 mg/L. These values compare

very favorably with the draft TMDL targets for estuarine waters at the Roosevelt Bridge published by FDEP, 0.74 mg/L TN and 0.081 mg/L TP.

Soil and Water Engineering Technology, Inc (2008) estimated the mean annual runoff to tide for the Tidal St. Lucie Basin, by land uses and loading rates, and calculated rainfall runoff for the South Tidal Basin at 14.3" annually and for the North Tidal basin at 12.7" annually. We selected the South Tidal basin for comparison to watersheds south of the St. Lucie River, and the North Tidal basin for the comparison to the Haney Creek basin.

Using the geometric means for TN and TP concentrations and the runoff over the acreage of the Frazier Creek Basin, we calculate annual basin discharge to be 599 acre-feet of stormwater, which when converted with measured concentrations to annual loading rates, provides 0.97 kg/acre TN and 0.12 kg/acre TP loading.

Total measured and calculated annual Frazier Creek Basin loads using SFMWD data are 488 kg TN and 58.4 kg TP. The B&H estimate for Frazier Creek Basin is 3,441 kg/year TN and 521 kg/year TP. Pro-rated by acreage, without regard for land use, from total estimated South Tidal St. Lucie loading, the Soil and Water Engineering Technology, Inc draft report indicates Frazier Creek loading would be 915 kg/year TN and 211 kg/year TP.

Airport Ditch

The Airport Ditch project was a joint City of Stuart/Martin County project that converted two box-cut drainage ditches that formerly drained uncontrolled to tide, one on the north perimeter of the Airport and one on the east perimeter, to wider linear wet retention/detention facilities controlled by "v" notched weirs. FAA required the littoral zone of the linear detention areas be hardened with concrete in order to deter feeding birds and thereby reduce conflicts between birds and airplanes, so there is no functional vegetated littoral zone in these improvements. The project was completed in 2000.

The Airport Ditch North receives drainage from an area of Stuart south and west of Krueger Creek and south of East Ocean Boulevard. This includes a large land area of residential single family on septic tanks, the north 1/3 of Airport property including half the runways, and a large area of institutional and commercial uses on both sides of Monterey Road and south of East Ocean. High density multifamily takes up the northeast corner of the watershed. The north Airport Ditch basin totals approximately 700 acres, about half in City and half in County jurisdictions. Very little of this area has stormwater quality treatment facilities, as most of it was built before they were required. The major conveyance system is open ditches.

The East Airport Ditch basin is approximately 300 acres, all in Martin County, comprising about ½ of the runways, open grassed and wooded land, most of the Martin County Golf Course, and single family residential land use along both sides of St. Lucie Boulevard that rely on septic tanks. We are not aware of any modern stormwater treatment facilities, except the ditch widening/linear detention and weir, in this basin.

SFWMD has monitored water quality downstream of the two existing weir outfall points from November 2001 to date, with data provided through April 2008. This station is located in the tidal section of the combined outfall for both North and East Airport Ditches, at St. Lucie Boulevard. Wide ranges in Specific Conductance in the data confirm the station's tidal location.

At the tidal outfall SFWMD reports TN median concentration is 0.80 mg/L, mean is 0.85 mg/L, and geometric mean is 0.82 mg/L. For TP, median concentration is 0.080 mg/L, mean is 0.103 mg/L, and geometric mean is 0.088 mg/L. These values also compare favorably with the draft TMDL targets for estuarine waters at the Roosevelt Bridge published by FDEP, although this basin outfall into the lower Middle Estuary several miles east and south of the Roosevelt Bridge.

Using the geometric means for TN and TP concentrations and the runoff over the acreage of the combined Airport Ditch Basins, we calculate annual basin discharge to be 1,192 acre feet of stormwater, when converted to loading rates, indicates 1.20 kg/acre TN and 0.13 kg/acre TP loading.

Total measured and calculated annual North and East Airport Ditch Basin loads are 1,205 kg TN and 108 kg TP. The B&H estimate (converted from City acreage to combined City and County acreage) for the combined Airport Ditches Basin is 6,836 kg/year TN and 1,112 kg/year TP. Pro-rated by acreage alone, without regard for land use, from total estimated South Tidal St. Lucie loading, the Soil and Water Engineering Technology, Inc, Airport Ditch North and East loading would be 1,819 kg/year TN and 419 kg/year TP.

Poppleton Creek

The first comprehensive watershed analysis within the City was prepared by LaConte Engineering with funding from the St. Lucie River Initiative, Inc; and donated to the City in 1998. Its initial purpose was to inventory the land within the Poppleton Creek watershed and classify it into three categories: land with no stormwater quality treatment facilities, modern stormwater treatment facilities, or partial treatment facilities. A "treatment deficit" in the watershed was identified, and a conceptual plan to construct a wet detention and filter marsh

facility adequate to provide at least 1" of treatment to all un- or partially treated developed land uses in the basin was included in the study.

The Poppleton Creek basin is approximately 525 acres in size. Land uses are primarily commercial, with a relatively high density residential area (Monterey Section, under County jurisdiction and on septic tanks) and medium density single family residential further north along both sides of Poppleton Creek. Most of the developed area remains on septic tanks. The principal drainage system consists of open ditches.

The final configuration of the Poppleton Creek Watershed Project includes four phases. The first phase, purchase of approximately 26 acres of undeveloped native habitat on both sides of the Creek for preservation and 12 acres of former flower farm for water quality treatment, was begun in 1998 and completed in 2007, the project delayed due to pesticide contamination and lengthy legal proceedings on the former flower farm.

The second phase, completed in 2004, consisted of removing exotic vegetation in the tidal Creek flood plain and accumulated muck sediments from the tidal portions of the Creek.

The third phase is under construction and consists of a 6.5 acre detention lake and weir system adjacent to a public park/trailhead access point. It should be completed in 2008.

The fourth and final phase will consist of the Willoughby Boulevard extension, a long-planned County roadway extension along the east side of the City watershed project. This final phase will add stormwater treatment capacity to accommodate both the Willoughby Extension and tributary segments of Federal Highway that were constructed prior to modern stormwater treatment standards.

SFWMD monitored Poppleton Creek from November 2001 through September 2003, with twice-monthly monitoring. The monitoring station was located at Kanner highway, which is tidal and below approximately 90% of the watershed. SFWMD reports TN median concentration is 0.765 mg/L, mean is 0.772 mg/L, and geometric mean is 0.756 mg/L. For TP, median concentration is 0.157mg/L, mean is 0.153 mg/L, and geometric mean is 0.147 mg/L. The TN values compare favorably with the draft TMDL targets for estuarine waters at the Roosevelt Bridge, although this basin outfall into the wide South Fork is west and several miles south (upstream) of the Roosevelt Bridge.

Using the geometric means for TN and TP concentrations and the runoff over the acreage of watershed upstream of the sampling point, we calculate annual basin discharge to be 563 acre

feet of stormwater, which when converted to loading rates indicates 1.11 kg/acre TN and 0.22 kg/acre TP loading.

Total measured and calculated annual Poppleton Creek Basin loads are 524 kg TN and 102 kg TP. The B&H estimate for the 472 acre Basin upstream of the sampling point is 3,228 kg/year TN and 482 kg/year TP. Pro-rated by acreage alone, without regard for land use, from total estimated South Tidal St. Lucie loading, Soil and Water Engineering Technology, Inc, estimates Poppleton Creek loading would be 860 kg/year TN and 199 kg/year TP.

Haney Creek

The Haney Creek watershed is approximately 800 acres in size, half under City jurisdiction and half under Martin County jurisdiction. The draft Soil and Water Engineering Technology report places it within the North Fork tidal basin, although it drains to the north side of the St. Lucie Middle Estuary via Haney Creek, just east of the Roosevelt Bridge.

Basin land uses vary, with older industrial uses in the County along Savannah Road and older single family residential areas along Baseline Avenue, and west of Federal Highway in North River Shores and Palm Lake Park. Both old and newer commercial uses extend north and east of Federal Highway. Extensive wetlands and upland buffers under conservation easements are found within newly developed residential areas in the north central basin, with both City and County conservation lands in the lower central basin. There is a new high school in the northwest corner of the basin and an older elementary school in the lower central portion. Both have modern stormwater treatment facilities.

The key feature of the lower basin is Arant's swamp, a roughly 35 acre tropical hardwood swamp that forms the headwaters of tidal Haney Creek. All the tributary areas to Haney Creek must first flow through some portion of Arant's Swamp.

The City's Haney Creek Watershed Project is elaborate, consisting of 13 major weirs and control structures, many acres of man-made ponds and emergent wetlands, restored wetlands, preserved native wetlands and uplands, and drainage flows redirected to maximize travel time and different types of water quality treatment.

The first phase completed in late 2003 included construction of a series of wet detention ponds and flow-through marshes with five weirs that gradually step groundwater levels down from above 10' elevation at the north end to 7.5' at the south end, where outfall to Arant's Swamp

begins via an existing ditch. Three native wetlands were also restored. Most of the drainage in the upper basin is now directed through this feature.

The second phase included redirecting drainage from Felix Williams elementary school and commercial properties to the northwest through a series of natural, restored and man-made wetlands controlled by weirs and control structures north and south of Baker Road and thence to the northwest corner of Arant's Swamp.

The third phase included expanding an old borrow pit, connecting it to restored wetlands, and directing these flows under Baseline Avenue and Baker Road to an existing ditch that ends in the southeast corner of Arant's Swamp.

The fourth phase included restoring and creating wetlands below the outfall of phase III, with a weir to raise groundwater and control flows into Arant's Swamp. It also included re-grading land around tidal Haney Creek south of SR 707 to expand tidal flood plain mangrove habitat and capture local stormwater runoff in shallow retention areas prior to overflow into the tidal flood plain.

During construction of the City's Haney Creek improvements, the County constructed a flow-through marsh watershed improvement project in Palm Lake Park that treats stormwater from this long-established residential community served by septic tanks prior to its release east under Federal Highway into the west end of Arant's Swamp.

SFWMD monitored Haney Creek from November 2001 through September 2003, with bi-weekly monitoring. The monitoring station was located at SR 707 highway, which is tidal and below approximately 99% of the watershed. SFWMD reports median TN concentration is 0.846 mg/L, mean is 0.815 mg/L, and geometric mean is 0.786 mg/L. For TP, median concentration is 0.158 mg/L, mean is 0.159 mg/L, and geometric mean is 0.150 mg/L. The TN values compare well with the draft TMDL targets for estuarine waters at the Roosevelt Bridge.

In order to remain consistent with the Soil and Water Engineering Technology methodology, we used the Tidal North Fork runoff and loading calculations from their draft report. Using the geometric means for TN and TP concentrations and the runoff over the acreage of watershed upstream of the sampling point, we calculate annual basin discharge to be 847 acre feet of stormwater, which when converted to loading rates indicates 1.03 kg/acre TN and 0.20 kg/acre TP loading.

Total measured and calculated annual Haney Creek Basin loads are 820 kg TN and 157 kg TP. The B&H estimate for the Basin upstream of the sampling point is 3,573 kg/year TN and 484 kg/year TP. Pro-rated by acreage alone, without regard for land use, from total estimated Tidal North Fork St. Lucie loading, the Soil and Water Engineering Technology, Inc, Haney Creek loading would be 1,240 kg/year TN and 288 kg/year TP.

City Watershed Comparisons

Two City watershed retrofit projects, Frazier Creek and Airport Ditch, have been monitored continuously since 2001. Both are meeting the draft TMDL requirements for nutrients nitrogen and phosphorus. These two watersheds comprise 929 acres of the total City jurisdiction of 4,227 acres, or 22% of the City.

Two City watershed retrofit projects, Haney Creek and Poppleton Creek, were monitored from November 2001 to September 2003, prior to construction of their respective retrofit projects. Both met the draft TMDL requirements for nitrogen, and both exceed the TMDL requirement for phosphorus by approximately 100%. These two watersheds comprise 1,325 acres, or 31% of the City jurisdiction.

Table 1 presents these four watersheds' summary nutrient concentrations. The close agreement between median, mean and geometric means for both nitrogen and phosphorus within watersheds indicates the water quality data are stable and representative of watershed behavior over the monitoring periods. All four watersheds appear to meet the draft nitrogen TMDL's.

Table 1

City of Stuart Watershed Projects Nutrient Concentrations at Outfalls to Tide in mg/L

Basin	Acres	Median N	Mean N	Geo Mean N	Median P	Mean P	Geo Mean P
Frazier Creek	503	0.630	0.690	0.660	0.073	0.085	0.079
Airport Ditch	1000	0.800	0.850	0.820	0.080	0.103	0.088
Poppleton Creek	525	0.765	0.772	0.756	0.157	0.153	0.147
Haney Creek	800	0.846	0.815	0.786	0.158	0.159	0.150

Notes: SFWMD data, Evergreen Engineering analysis, 2008

Close agreement between monitoring results for post-retrofit watersheds and for pre-retrofit watersheds suggests that the retrofit projects are successful in reducing phosphorus concentrations to the TMDL target levels. Slightly better performance of the Frazier Creek versus Airport Ditch retrofits would be expected given the much more elaborate design of the Frazier retrofit, and the fact that Martin County Golf Course is within the Airport Ditch watershed. However, it is surprising that simple, linear wet detention/weir systems such as constructed in Airport Ditch just above outfall to tide appear to be providing better phosphorus attenuation than literature sources would predict.

Table 2 shows Ortho-phosphorus concentrations as a percentage of total phosphorus for all four watersheds. The Frazier and Airport watersheds show a smaller percentage of reactive P than the Haney and Poppleton watersheds, which have higher gross concentrations and higher percentages of reactive P than the two post-retrofit watersheds. These results suggest it is plausible that the post-retrofit performance of Haney and Poppleton may be similarly improved to the TMDL standards.

Table 2

City of Stuart Watershed Projects Reactive Phosphorus Concentrations at Outfalls to Tide in mg/L

Basin	Acres	Median OPO4	Mean OPO4	Geo Mean OPO4	% of TP
Frazier Creek	503	0.014	0.023	0.016	20.3
Airport Ditch	1000	0.056	0.033	0.037	42.0
Poppleton Creek	525	0.115	0.116	0.109	74.1
Haney Creek	800	0.106	0.116	0.108	72.0

Notes: SFWMD data, Evergreen Engineering analysis, 2008
%TP = geomean OPO4 divided by geomean TP

Table 3 shows reactive nitrogen nitrates and nitrites. The post-retrofit Frazier and Airport watersheds average less than half the ammonium ion concentration of the pre-retrofit watersheds Poppleton and Haney. NOX is relatively low for the retrofit watersheds and for Haney Creek. We postulate that Arant's swamp is serving a denitrification function for the Haney Creek basin, while Poppleton Creek has no swamp between the basin and outfall to tide, and behaves more typically of urban watersheds.

Table 3

City of Stuart Watershed Projects Reactive Nitrogen Concentrations at Outfalls to Tide in mg/L

Basin	Median NH4	Mean NH4	Geo Mean NH4	% of TN	Median NOX	Mean NOX	Geo Mean NOX	% of TN
Frazier Creek	0.023	0.075	0.030	4.5	0.030	0.095	0.032	14.4
Airport Ditch	0.081	0.064	0.056	6.8	0.052	0.028	0.030	3.4
Poppleton Creek	0.125	0.138	0.119	15.7	0.059	0.090	0.056	11.9
Haney Creek	0.074	0.089	0.075	9.5	0.035	0.053	0.036	6.7

Notes: SFWMD data, Evergreen Engineering analysis, 2008
%TN = sum geomeans NH4 and NOX divided by geomean TN

Airport Ditch has the highest reported TN of any of the watersheds at 0.82 ppm, and the lowest percentage of reactive nitrogen species. This indicates organic nitrogen, very difficult to substantially reduce with wet detention, is the principal N export from this basin. Comparing reactive nitrogen to ortho-phosphorus concentrations in Airport Ditch, it appears nitrogen is limiting in that system. It appears likely that the Poppleton and Haney Creek retrofits will reduce NH4 to levels closer to those observed in the Frazier and Airport Ditch Watersheds, with NOX being more problematic to reduce in Poppleton than in Haney, where it is already low.

The four watersheds analyzed herein have many common elements. All are of similar size, all contain a substantial percentage of deep, sandy soils, none have significant agricultural land uses, all are mostly built out with a mix of old and new urban land uses, and all historically maximized drainage to tide without regard for water quality.

The retrofit projects are all designed to maximize groundwater storage in the areas of transition from freshwater to estuarine ecosystems via weirs, all are designed to very gradually bleed stored groundwater to tide over long periods, and all are designed for high flow during major storm events to maintain flood protection.

There are also some important differences between the four watersheds. Frazier Creek is almost 100% urban with very little acreage in conserved native uplands or wetlands, while Haney, Poppleton and Airport watersheds all have significant native uplands and Haney has significant acreages of a variety of wetlands as well. Most residential land uses in Poppleton and Airport watersheds are on septic tanks, while most in Haney and Frazier watersheds are on

central sanitary sewers. Reactive nitrogen species concentrations, currently presenting substantially higher in the Poppleton Creek than Airport Ditch watersheds, will be interesting to observe in Poppleton post-retrofit water quality data.

Land Use and Nutrient Loading

Table 4 shows 2005 estimates for average City of Stuart nutrient loading made by Berryman & Henigar, assuming the four watershed retrofit projects are all completed, all urban storm sewers with direct outfalls to tide are retrofit with baffle boxes, and existing stormwater management facilities within the basins are maintained in proper operational order. These four watersheds combined represent 53% of the City's land area.

Table 4

City of Stuart Watershed Projects Estimated Nutrient Loading Rates in kg/acre/year

Data Source		B&H		SWETI		SFMWD/EEI	
Basin	Acres	TN	TP	TN	TP	TN	TP
Frazier Creek	503	6.520	0.779	1.820	0.420	0.970	0.120
Airport Ditch	1000	6.370	0.777	1.820	0.420	1.200	0.130
Poppleton Creek	525	6.020	0.690	1.820	0.420	1.110	0.220
Haney Creek	800	4.220	0.480	1.550	0.360	1.020	0.200

Notes:
B&H = Berryman & Henigar, 2005
SWETI = Soil and Water Engineering Technology, Inc, 2008
SFWMD = South Florida Water Management District, 2008
EEI = Evergreen Engineering, Inc., 2008

These loading estimates are then compared to draft Soil and Water Engineering Technology, Inc loading rates. These are averages for the total South and North Tidal Basins' land uses, applied to the City watersheds within them.

The final two columns are derived from SFWMD water quality data using Soil and Water Engineering Technology estimates of annual rainfall runoff. It is obvious that estimated and actual nutrient loads in City drainage differ, with the actual loading being far less than estimates. It is also clear that the two retrofit watersheds perform about twice as well as the pre-retrofit watersheds with respect to phosphorus attenuation, but that total nitrogen loading

is not substantially different between the four. Reactive nitrogen is higher in pre-retrofit Poppleton Creek (Table 3).

It is important to note that estimates of nutrient loading in tons/year depends both on assumptions about background land use loading rates, and on assumed rainfall runoff. If runoff rates are higher than SWEI estimates, using SFWMD measured concentrations for nutrients will calculate into higher annual nutrient loading than shown here. On the other hand, the City's watershed retrofit projects rely heavily on groundwater storage as a water quality and quantity management technique, so it is also possible that using an average runoff rate for the City over-estimates annual pollutant loading per acre for many watersheds. This issue should be further clarified when SFMWD makes flow rate data available.

Conclusions

The SFWMD water quality monitoring data set show the Frazier and Airport Ditch post-retrofit Watershed Projects are producing stormwater that meets draft TMDL requirements for nitrogen and phosphorus. Pre-retrofit Haney and Poppleton Creek Watersheds meet the draft nitrogen TMDL but not the phosphorus TMDL. Post-retrofit Haney and Poppleton Watershed Projects are anticipated to meet the phosphorus TMDL.

The SFWMD data provide a means of comparing actual watershed performance with previous estimates based on predicted nutrient loading for various land uses. Land use/nutrient loading estimates substantially exceed reality for the four City of Stuart watersheds for which we have water quality data. It follows that these loading estimates are not accurate enough in the City to justify significant public expenditures for additional best management practices over and above those already implemented.

The City's basic watershed retrofit design parameters, staging groundwater up to the maximum extent possible over a large land area and releasing it slowly to tide, with deep "v" notched weirs, appears to be more effective for nutrient control in stormwater runoff than literature sources focused on surface water volume and detention/retention time of various best management practices predict. Generally favorable soils conditions in the City for storing groundwater above the freshwater/tidal interface are likely an important factor.

Recommendations

SFWMD's water quality monitoring program should be continued. It is a highly valuable data set and will prove more valuable as public and private investments in nutrient load attenuation

are made. Data collection at Frazier and Airport Ditch should be relocated to Poppleton and Haney Creeks to collect data on post-retrofit conditions for those watersheds.

SFWMD's data set should be further mined for both nutrient hot spots and cold spots, equipment moved accordingly, and hot spots addressed. Simple linear detention in uncontrolled outfalls to tide may offer much more "bang for the buck" than is generally appreciated.

Once TMDL's are final, the City should collaborate with Martin County on shared-basin Basin Management Action Plans for hot spot basins in the County which also have some lands in City jurisdiction. Pending collection of data to evaluate performance of the post-retrofit Haney and Poppleton basins, there does not appear to be much to map in the City at this time.