Santa Fe
Algal Turf Scrubber®
Pilot Program

Final Performance Report

February 16, 2010 – February 22, 2011

Contract # 08/09-151

Prepared for:

Suwannee River Water Management District

Prepared by:

HydroMentia
WATER TREATMENT TECHNOLOGIES

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EXECUTIVE SUMMARY

Project Background and Intent

- The Santa Fe Algal Turf Scrubber® Pilot Program was funded by the State of Florida, and Administered by the Suwannee River Water Management District (SRWMD), for the purpose of determining the cost effectiveness of applying the Algal Turf Scrubber® or ATS™ within the Suwannee River Basin for reduction of nutrient loadings associated with the Suwannee River System.

- The ATS™ is a proprietary technology assigned to HydroMentia, Inc. of Ocala, Florida. ATS™ is a managed aquatic plant system which relies upon direct biological uptake and certain physical and chemical phenomenon to extract nutrients from a continuous flow from a targeted water source. This is done through the cultivation of an attached algal community known as algal turf upon a sloped floway over which water moves as a shallow, laminar, pulsed or surged flow. Cultivation means the purposeful growth and maintenance of this algal turf community through controlled flow delivery rates and periodic harvesting.

- Operational, maintenance, monitoring and reporting responsibilities for the pilot project were delegated to HydroMentia, through a contract with the Suwannee River Water Management District (DISTRICT) (Contract 08/09-151 dated June 30, 2009) and a subcontract between HydroMentia and the University of Florida (Contract 08/09-151UF dated September 15, 2009).

- For a one year project term from February 16, 2010 to February 22, 2011, two parallel, 500 foot long, one foot wide, Algal Turf Scrubber® (ATS™) Mobile Pilot Units (MPU) floways were operated and their performances monitored and recorded. The units were installed near the upstream reaches of the Santa Fe River in northern Alachua County, Florida--the Santa Fe River being tributary to the Suwannee River and part of the Suwannee River Basin. The Suwannee River eventually releases its waters to the Gulf of Mexico just south of Florida's panhandle bend.

- The property upon which the pilot unit was located is owned and maintained by the University of Florida's Institute of Food and Agricultural Sciences (IFAS). The unit labeled SF1 was operated exclusively by HydroMentia, who applied their normal operational procedures and protocols. The operational approach for the second unit, labeled SF2, was per the University of Florida in accordance with the agreement between HydroMentia and the University of Florida.

- The investigation strategy was to document performance of the ATS™ technology for the specific conditions attendant with the Santa Fe River through the normal operational efforts applied to SF1 by HydroMentia, while expanding the understanding of the dynamics of the ATS™ process through more detailed evaluations on SF2 by the University of Florida, with the intent of ultimately facilitating system optimization. Specific evaluations and findings by the University of Florida are included in a separate report.

System Flow and Algal Productivity

- Unlike all previous quarters, Q4 was not represented by continuous system operations, as it was necessary to shut down the influent pumping units from December 21, 2010 to January 11, 2011 because of the absence of flow at the intake zone of the Santa Fe River.

- Influent flow throughout the project monitoring period was mostly continuous except for a few short term periods of power loss and the extended shut down due to lack of flow within the Santa Fe River during Q4. Flows were delivered to both floways equally, averaging 18.4 gpm for the project term.

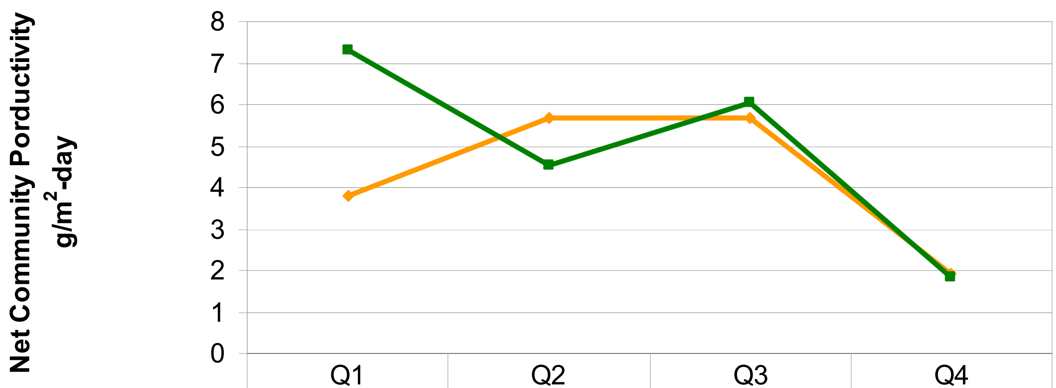
- The start-up and stabilization period of the Algal Turf Scrubber® is similar to other autotrophic water treatment systems, where optimal performance is achieved only after the initial start-up and stabilization phases[1]. While the start-up and stabilization period for the ATS™ is of shorter duration than a treatment wetland, performance during the initial 12 months of operation should be considered a conservative estimate of treatment potential for the Algal Turf Scrubber® system.

- In Q3 algal productivity increased from Q2 even though inflow water temperature, nitrogen concentration and phosphorus concentration all decreased. This increase in productivity was counter to expected changes in productivity with decreasing temperatures and nutrient levels, and indicates that through Q3 the algal turf community remained in a Start-up and Stabilization Phase.

- During Q4 low water temperatures, low nitrogen levels, and low river levels influenced system performance, and algal turf productivity and nutrient reduction rates were the lowest of the project term. This response is consistent with expected impacts of these factors upon biological growth dynamics, indicating the system may have achieved the Fully Operational Phase.

- For the project term, the algal turf net community productivity, as calculated from recovered biomass averaged 4.57 and 5.04 dry-g/m^2-day for floways SF1 and SF2, respectively. The productivity trend over the four quarters is illustrated in Figure ES-1. As noted, productivity during Q4 was the lowest of the four quarter period for both floways.

- Algal productivity was low relative to other ATS™ systems operated in Florida. Low productivity appears to be in response to low available carbon (low alkalinity) and low available nitrogen (low nitrate-N) within the Santa Fe River.



	Q1	Q2	Q3	Q4
SF1 Net Community Productivity dry-g/m2-day	3.82	5.67	5.67	1.92
SF2 Net Community Productivity dry-g/m2-day	7.29	4.51	6.04	1.85

Figure ES-1: Comparative Algal Turf Community Net Productivity

[1] 2008. Florida Department of Environmental Protection and South Florida Water Management District. Fact Sheet for FDEP Industrial Wastewater Permit No. F10300195

Nitrogen Reduction

- Mean influent TN concentration during the monitoring period was 1.07 mg/l, while TN effluent concentrations were 0.88 mg/l and 0.94 mg/l for Floway SF1 and SF2, respectively. The mean influent NOx-N concentrations for both floways during the monitoring period was O.12 mg/L, with effluent NOx-N concentrations at 0.05 mg/l for both floways.

- Project influent and effluent NOx-N concentrations were 66% and 86% lower than the long-term target NOx-N concentration for the Suwannee River (0.35 mg/L).

- Over the four quarters, the performance in terms of nutrient reduction was similar for the two parallel floways, although SF2 showed a lower removal rate for Total Kjeldahl Nitrogen (TKN) as shown in Table ES-1.

Table ES-1: Summary of NOx-N, TKN, and TN Percentage Mass Removal through the Project Monitoring Period.

Floway	NOx-N Percent Removal	Total Kjeldahl-N Percent Removal	Total Nitrogen Percent Removal
SF1	56%	14%	19%
SF2	56%	7%	12%

- Floway SF1 achieved a 56% reduction in NOx-N, and 14% and 19% reductions in Total Kjeldahl-N (TKN) and Total Nitrogen (TN), respectively. Floway SF2 achieved a 56% reduction in NOx-N, and 7% and 12% reductions in TKN and TN, respectively. Compared to the other forms of nitrogen, the system removed a noticeably greater percentage of NOx-N. This is consistent with other ATS™ systems in which biologically readily available forms of nitrogen (NOx-N and NH3-N) serve as a primary source of nitrogen to the algal turf.

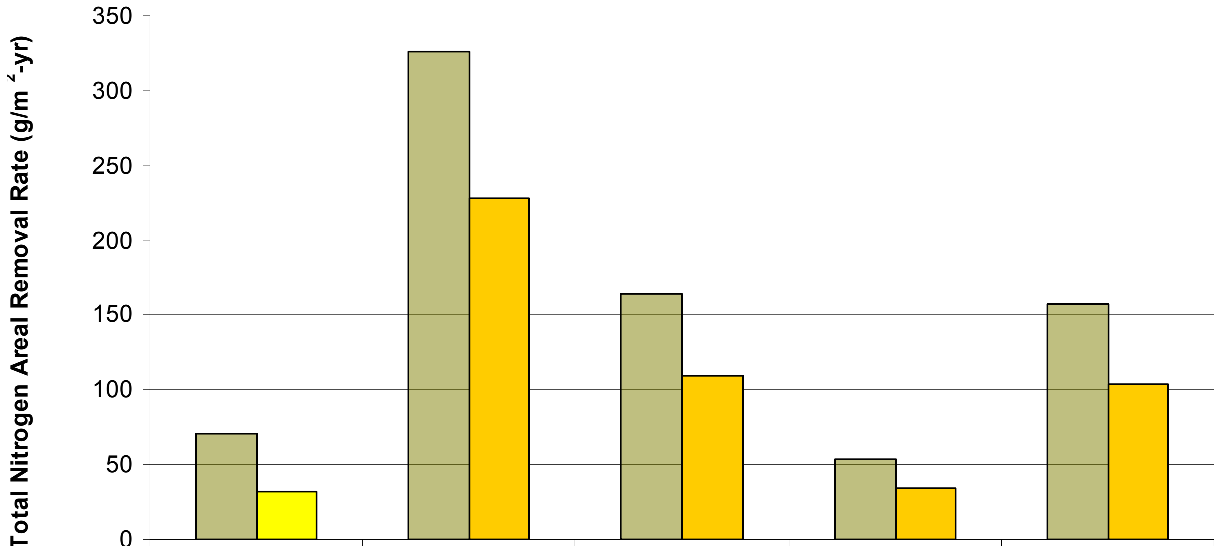
- Areal removal rate is an important performance metric as is relates to treatment performance, land requirements, and ultimately pollutant recovery costs. The higher the areal removal rate the lower the land requirement for a given removal target.

- System performances in terms of areal removal rate expressed as g/m^2-year for Nitrate + Nitrite Nitrogen (NOx-N), Total Nitrogen (TN), and TKN are shown in Table ES-1 and Figures ES-2, ES-3 and ES-4.

- TN mean areal removal rates for the project monitoring period were 158 g/m^2-yr and 104 g/m^2-yr, respectively, with mean NOx-N areal removal rates of 54 g/m^2-yr. Due to the relatively low concentrations of NOx-N, areal removal rates of NO-x-N were limited, as the ATS™ system reduced NOx-N concentrations to 0.05 mg/l part way down the floway. Higher rates can be expected at higher NOx-N concentrations.

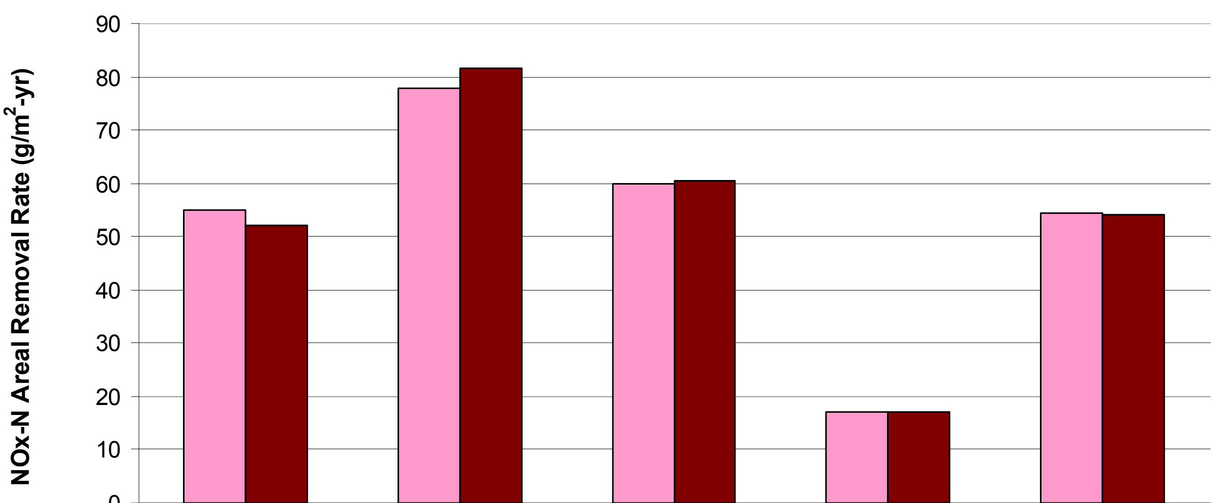
Table ES-2: Summary of NOx-N, TKN, and TN Areal Removal Rates through the Project Monitoring Period.

Floway	NOx-N Areal Removal Rate (g/m^2-yr)	Total Kjeldahl - N Areal Removal Rate (g/m^2-yr)	Total Nitrogen Areal Removal Rate (g/m^2-yr)
SF1	54	103	158
SF2	54	49	104



	Q1	Q2	Q3	Q4	Monitoring Period YTD
	TN Inflow = 1.10 mg/L NOx Inflow = 0.11 mg/L TP Inflow = 0.213 mg/L	TN Inflow = 1.31 mg/L NOx Inflow = 0.17 mg/L TP Inflow = 0.300 mg/L	TN Inflow = 1.05 mg/L NOx Inflow = 0.13 mg/L TP Inflow = 0.252 mg/L	TN Inflow = 0.75 mg/L NOx Inflow = 0.06 mg/L TP Inflow = 0.250 mg/L	TN Inflow = 1.06 mg/L NOx Inflow = 0.12 mg/L TP Inflow = 0.256 mg/L
Flow ay SF1	71	326	164	53	158
Flow ay SF2	32	228	110	34	104

Figure ES-2: Comparative System Performance Total Nitrogen Areal Removal Rates



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Floway SF1	55	78	60	17	54
Floway SF2	52	82	61	17	54

Figure ES-3: Comparative System Performance NOx-N Areal Removal Rates

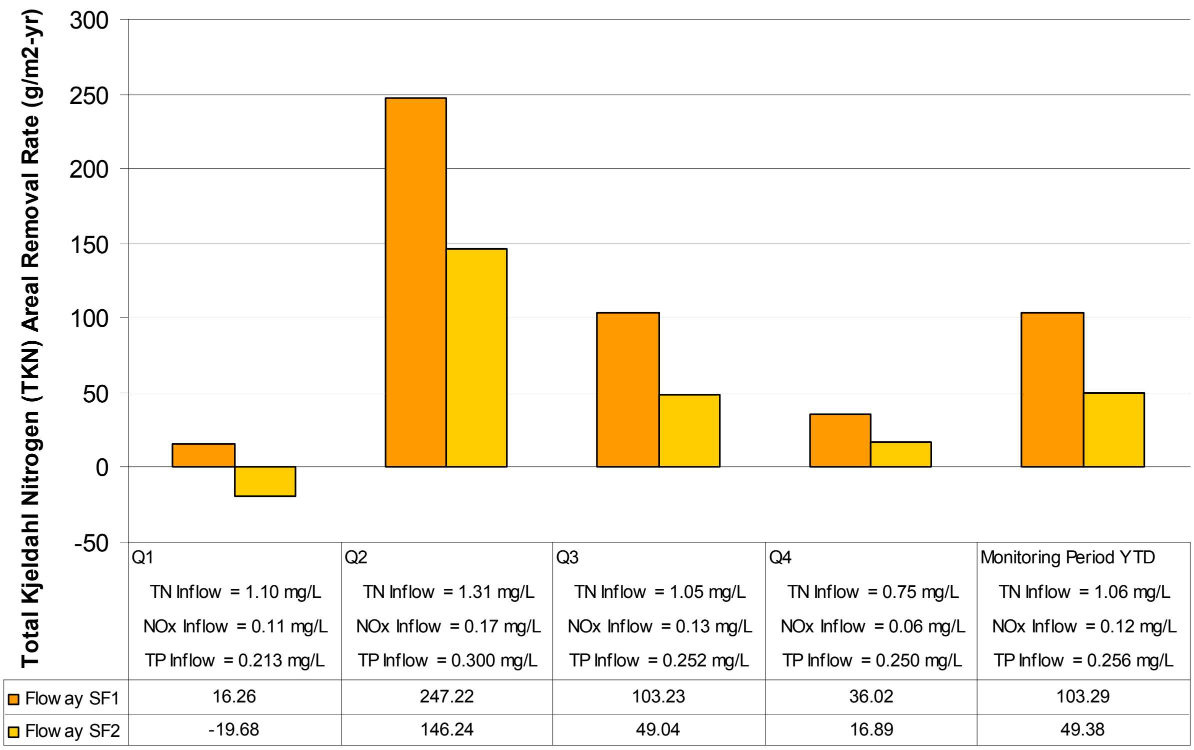


Figure ES-4: Comparative System Performance TKN Areal Removal Rates

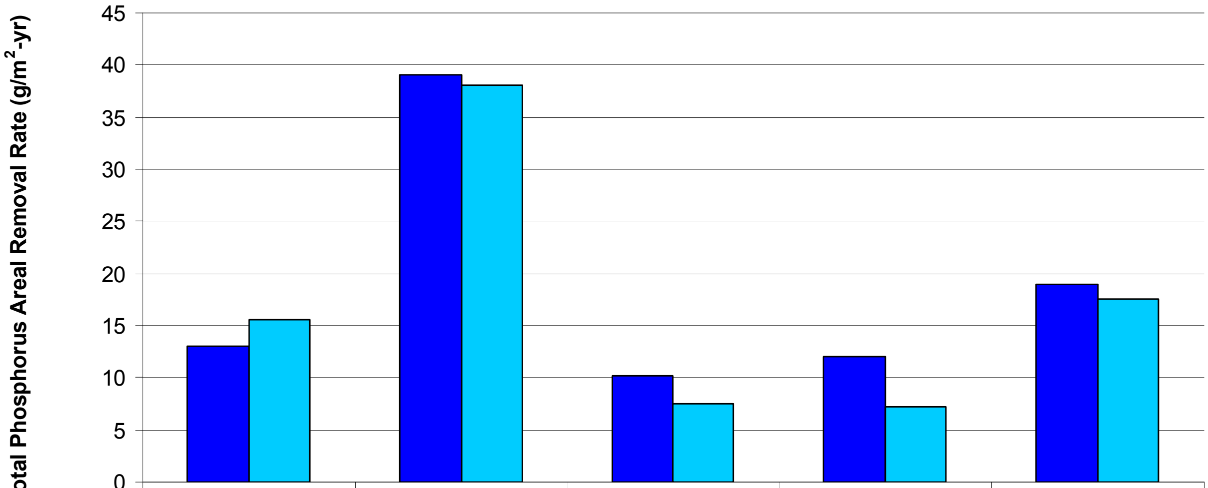
Phosphorus Reduction, Available Carbon and Dissolved Oxygen

- Total phosphorus concentrations and loads, while not identified as a cause of impairment in the Suwannee River systems, have increased above historic background levels. Accordingly, reductions in total phosphorus will benefit the system.

- Total phosphorus mean influent concentration to both floways for the project period was 254 ppb with effluent concentrations at 232 ppb and 228 ppb for Floways SF1 and SF2, respectively. Total phosphorus percent removal rates and areal removal rates are shown in Table ES-3. Total phosphorus removals were at 10% and 9% in floways SF1 and SF2, respectively. Total phosphorus areal removal rates were 19 g/m2-yr and 18 g/m2-yr for Floways SF1 and SF2, respectively. These removal rates are over 10 times greater than rates typical of treatment wetlands.

Table ES-3: Summary of Phosphorus Percentage Mass Removal through the Project Monitoring Period.

Floway	Total Phosphorus Percent Mass Removal	Total Phosphorus Areal Removal Rate (g/m^2-yr)
SF1	10%	19
SF2	9%	18



	Q1	Q2	Q3	Q4	Monitoring Period YTD
	TN Inflow = 1.10 mg/L	TN Inflow = 1.31 mg/L	TN Inflow = 1.05 mg/L	TN Inflow = 0.75 mg/L	TN Inflow = 1.06 mg/L
	NOx Inflow = 0.11 mg/L	NOx Inflow = 0.17 mg/L	NOx Inflow = 0.13 mg/L	NOx Inflow = 0.06 mg/L	NOx Inflow = 0.12 mg/L
	TP Inflow = 0.213 mg/L	TP Inflow = 0.300 mg/L	TP Inflow = 0.252 mg/L	TP Inflow = 0.250 mg/L	TP Inflow = 0.256 mg/L
Floway SF1	13.08	39.05	10.25	12.00	18.91
Floway SF2	15.60	38.11	7.53	7.23	17.56

Figure ES-5: Comparative System Performance Total Phosphorus Areal Removal Rates

- Alkalinity levels were comparatively low within the Santa Fe influent, averaging about 34 mg/l as $CaCO_3$ for the project term. With such low alkalinities, when pH levels are higher than 7.00, conditions are established for available carbon to become growth limiting. For the project term there was considerable variation in influent pH, ranging from 6.62 (Q1) to 7.38 (Q3). Low carbon availability may have impacted productivity within both floways, along with low levels of available nitrogen. In downstream stretches of the Santa Fe River and the Suwannee River both alkalinity and available nitrogen concentrations are much higher, and it would be expected that this would promote higher algal turf productivity and improved system performance.

- The ATS™ increased dissolved oxygen levels 60.6% for Floway SF1 from 7.1 mg/l to 11.4 mg/l, and 58.3% from 7.2 mg/l to 11.4 mg/l for Floway SF2.

Comparison to Performance Projections

- In September of 2006, at the request of the Suwannee River Water Management District, HydroMentia a *Preliminary Engineering Assessment for a Comprehensive Algal Turf Scrubber Based Nutrient Control Program for the Suwannee River in Florida*. The document was intended to provide an initial assessment of the application of the Algal Turf Scrubber® technology as a regional treatment system to meet District nitrogen reduction goals. For this conceptual effort, the Suwannee River reduction target for nitrate-nitrogen was set at 30% or about 1,314 tons per year. Based on the Preliminary Engineering Assessment, it was determined that a total of 120 treatment modules would be required to meet the desired 30% nitrogen reduction goal. The total effective treatment area for the 120 modules was 1440 acres.

- Performance modeling results for the 2006 Preliminary Engineering Assessment were based on operation of the 120 modules (full build-out) at NOx-N inflow concentrations that averaged 0.31 mg/l, and alkalinity concentrations that average 118 mg/l as CaCO3. Total nitrogen and NOx-N areal removal rates were projected to be 296 g/m^2-yr and 199 g/m^2-yr, respectively based on Algal Turf Scrubber® Design Model (ATSDEM) modeling.

- In 2008 the Florida Department of Environmental Protection (FDEP) established a nutrient and dissolved oxygen (DO) Total Maximum Daily Load (TMDL) for the Suwannee and Santa Fe Rivers. The target long-term nitrate average was 0.35 mg/L. To achieve the annual average nitrate target of 0.35 mg/L in the Suwannee and Santa Fe River basins, the nitrate loads from the nonpoint source related to Middle Suwannee, Lower Suwannee and Santa Fe rivers need to be reduced by 51%, 58% and 35%, respectively.

- The Santa Fe ATS™ pilot was proposed to be a pilot scale investigation of the Algal Turf Scrubber® (ATS™) to simulate the ATS™ treatment process specific to the water quality conditions associated with Santa Fe River. The results would be used to (i) verify periphyton growth projections and treatment performance developed in preliminary Algal Turf Scrubber Design Model (ATSDEM) projections applied in the 2006 Preliminary Engineering Assessment and to (ii) optimize the design of full-scale Algal Turf Scrubber® systems within the Suwannee River watershed.

- Provided in Table ES-4 are comparative data for influent water quality, algal productivity, and nitrogen areal removal rates for the two pilot Santa Fe ATS™ Floways, the 2006 Suwannee River Engineering Assessment and for comparison an Algal Turf Scrubber® pilot operating in Indian River County, Florida at higher levels of alkalinity and available nitrogen.

Table ES-4: Summary of NOx-N, TKN, and TN Percentage Mass Removal through the Project Monitoring Period.

System	Floway Length (ft)	LHLR (gpm/lf)	TP Inflow (ppb)	TN Inflow (mg/l)	NOx Inflow (mg/l)	NH3 Inflow (mg/l)	Alkalinity (mg/l)	Algal Productivity (dry-g/m2-yr)	Nitrogen Areal Removal Rate (g/m2-yr)
Santa FE ATS™ Pilot - SF1	500	18.4	254	1.07	0.12	*	25	5	158
Santa FE ATS™ Pilot - SF2	500	18.4	254	1.07	0.12	*	25	5	104
2006 Suwannee River Prelim Eng Assessment	600	20.0	117	1.14	0.31	*	118	27	296
2011 Indian River County ATS™ Pilot	500	18.8	130	0.95	0.08	0.33	353	19	312

- Nitrogen areal removal rates of 158 g/m^2-yr and 104 g/m^2-yr for Floways SF1 and SF2 were 47% and 65% lower than the 2006 Preliminary Engineering Assessment. These lower removal rates are consistent with the 61% lower influent nitrate-nitrogen (NOx-N) and 73% lower alkalinity concentrations for the Santa Fe River as compared to the Suwannee River values used in the 2006 Preliminary Engineering Assessment.

- Low available carbon and low available nitrogen reduce algal productivity and nutrient uptake in algae based systems such as the Algal Turf Scrubber®. Accordingly, higher alkalinities and higher NOx-N levels such as those found in the Middle and Lower Suwannee River will provide higher available carbon and nitrogen, which is projected to result in higher algal productivity, less pH fluctuation down the floway, and increased nitrogen recovery rates. An example of the higher nitrogen areal removal rates under these conditions is documented by the performance of the Indian River County ATS™ Pilot as shown in Table ES-4.

- Operating at the relatively low available nitrogen and alkalinity concentrations of the Santa Fe River near the Boston Farm, the ATS™ pilot project provides a conservative estimate of NOx-N removal for ATS™ systems applied to the Suwannee River.

Final Conclusions and Recommendations

- Based on the Santa Fe ATS™ Pilot test results, the Algal Turf Scrubber® nitrogen removal performance is consistent with projections provided in the 2006 Preliminary Engineering Assessment.

- The Algal Turf Scrubber® can effectively reduce NOx-N and TN loads in the Suwannee River watershed, thereby providing a regional option to meet TMDL nitrogen load reduction goals.

- The ATS™ system primarily reduces biologically available nitrogen such as NOx-N, thereby maximizing treatment benefits for the Suwannee River.

- Testing on the relative low NOx-N and low alkalinity waters associated with the Santa Fe River near Boston Farm confirms that the Algal Turf Scrubber® technology will achieve high rates of NOx-N removal even as concentrations in the Suwannee River are reduced towards the long-tem NOx-N target of 0.35 mg/l.

- The ATS™ system increased dissolved oxygen levels 58% to 61%. As a secondary benefit of ATS™ nitrogen treatment, increased oxygen levels associated with ATS™ discharges would benefit receiving waters in the Suwannee and Santa Fe River watersheds that are currently impaired due to low oxygen levels.

- It is recommended that the Santa Fe ATS™ pilot investigation be extended, and that supplementation with bicarbonate to increase alkalinity and NOx-N be included in an effort to emulate downstream conditions within the Middle and Lower Suwannee River system to provide for an optimized ATS™ design for Suwannee River water quality, and that more extensive monitoring of alkalinity and ammonia nitrogen be conducted.

- It is recommended that one Santa Fe ATS™ floway be operated with Santa Fe River as source water, with the second flow receiving flow supplemented with bicarbonate and NOx-N as described above.

- It is recommended that biomass recovered from the Santa FE ATS™ pilot be evaluated by USDA-ARS researchers in regard to its potential product value within the Florida agricultural community. USDA-ARS researchers recently entered a 5-year research program to investigate the Algal Turf Scrubber® technology and algal products produced from the system.

SECTION 1. PROJECT BACKGROUND

Project History and Review

The Suwannee River, with its headwaters in the Okefenokee Swamp in south-central Georgia, continues for approximately 235 miles (378.1 km) to empty into the Gulf of Mexico on the northwestern coast (Big Bend area) of Florida. Though less than 50% of the Suwannee basin is actually located within Florida, the Suwannee River is Florida's second largest river.

Water quality monitoring has revealed a relatively recent pattern of extensive nitrate-nitrogen loading of the Suwannee River from groundwater sources, with artesian spring discharges implicated as a major nitrate source. This heavy influx of nitrate-nitrogen, and to some extent phosphorus, presents significant challenges. Not only do these nutrient loads result in ecological impairment within the surface water resources associated with the Suwannee Basin, but they impose upon the estuarine and marine waters of the Gulf of Mexico.

It has been generally recognized that if the water quality and ecological integrity of aquatic systems within the Suwannee River Basin are to be restored and sustained such that they meet the conditions set by local, state and Federal regulations, nutrient loadings will need to be managed and reduced through innovative, long-term programs.

These programs begin with implementation of on-site best management practices to reduce the quantity of nutrient pollutants that are transported off-site to groundwater and surface water. These BMPs are of particular importance to the agricultural industry as nutrients can represent a valuable resource relative to crop production, therefore minimizing nutrient losses results in economic benefits. However, it is also recognized that nutrients associated with animal wastes at the relatively higher bulk densities are more costly to store, transport and apply to crops throughout a region. Therefore animal waste based nutrients are often applied locally at maximum allowed rates, while inorganic fertilizer is imported into the watershed for crop production. BMPs offer opportunities to address many of these challenges; however experts in the field do not believe that BMPs alone will be able to achieve the required pollutant load reductions (Don Graetz, Personal Communication). In addition to the employment of BMPs, cost-effective treatment technologies will need to be employed on a regional scale to meet the desired nutrient load reductions.

The Algal Turf Scrubber® (ATS™) is one technology that could well be a contributing component of such a program, as it has been shown effective in facilitating nutrient reduction from native surface waters in which nitrogen and phosphorus levels, while comparatively low, still require further reduction. Additionally, ATS™ has shown ability to substantially reduce nitrate levels (>50%), even from low nutrient waters. This is relevant because of the suspected deleterious impact of nitrate upon spring fed streams and rivers in Central and Northern Florida.

In 2006, at the request of the Suwannee River Water Management District, HydroMentia Inc. was asked to evaluate how the Algal Turf Scrubber® technology might be employed to reduce nitrogen loads from the Suwannee River to the Gulf of Mexico. In September of 2006, HydroMentia submitted to the District a Preliminary Engineering Assessment for a Comprehensive Algal Turf Scrubber Based Nutrient Control Program for the Suwannee River in Florida. The document was intended to provide an initial assessment of the application of the Algal Turf Scrubber® technology as a regional treatment system to meet nitrogen reduction goals. For this conceptual effort, the Suwannee River reduction target for nitrate-nitrogen was set at 30% or about 1,314 tons per year.

The proposed strategy for development of an ATS™ based regional treatment program for the Suwannee River was to establish treatment sites consisting of multiple 25 MGD modules operated in parallel at strategic points between problematic portions of the river—primarily the portion known as the Middle

Suwannee between Ellaville in Suwannee County to Fanning Springs in Levy County. These regional treatment sites would be sized based upon site availability, accessibility, and layout, and the adjusted water quality of the river at the site. Using this system approach, the overall program could be developed incrementally, allowing coordination with other District nutrient reduction programs.

Based on the preliminary engineering assessment, it was determined that a total of 120 treatment modules would be required to meet the desired 30% nitrogen reduction goal. Influent to the ATS™ treatment units came directly from the Suwannee River. Influent nitrate concentrations ranged from 0.17 to 0.37 mg/l (mean = 0.31 mg/l) based upon conditions at full build-out. The modules in the preliminary assessment were to be located at 11 sites, with the number of modules per site ranging from 2 to 24. The total effective treatment area for the 120 modules was 1440 acres. At full build out the ATS™ program was projected to achieve a 1,282 ton/yr or 29.3 percent reduction in nitrate-N and 1,906 ton/yr or 22.8 percent reduction in total nitrogen. The projected nitrate-N and total nitrogen areal removal rates were 199 g/m^2-yr and 296 g/m^2-yr, respectively.

In 2008 the FDEP established a nutrient and dissolved oxygen (DO) Total Maximum Daily Load (TMDL) for the Suwannee and Santa Fe Rivers. TMDLs for the Suwannee and Santa Fe River Basins were expressed in terms of concentration of nitrate (mg/L), and percent reduction of nitrate and represent the maximum long-term nitrate concentration the SRB can assimilate and still maintain a balanced aquatic flora or fauna.

The target long-term nitrate average concentration was established as 0.35 mg/L. To achieve the annual average nitrate target of 0.35 mg/L in the Suwannee and Santa Fe River basins, it was determined that the nitrate loads from the nonpoint sources related to Middle Suwannee, Lower Suwannee and Santa Fe rivers, needed to be reduced by 51%, 58% and 35%, respectively.

Algal Turf Scrubber® System

The proposed Algal Turf Scrubber® Based Nutrient Control Program presented in the 2006 Preliminary Engineering Assessment offers a number of advantages when considering available approaches for nutrient load reduction in the watershed. These benefits include relatively low land requirements and the capacity to cost-effectively recover nutrient pollutants from high flow, relatively low concentration impaired surface waters. As an additional benefit, the proposed Algal Turf Scrubber® nutrient control program is ideally suited for phased implementation.

In order to field verify levels of Algal Turf Scrubber® treatment performance projected in the 2006 Preliminary Engineering Assessment, the Suwannee River Water Management District (DISTRICT) decided to pursue development and implementation of an ATS™ pilot program. Consequently a plan of study was developed through a series of discussions with HydroMentia, the purveyor of the technology; the University of Florida (UF); and the DISTRICT. Eventually a specific pilot program, entitled the Santa Fe River[2] Algal Turf Scrubber® (ATS™) Pilot Project (SF-Pilot), was delineated within a contract between HydroMentia, inc. and the Suwannee River Water Management District (DISTRICT) (Contract 08/09-151 dated June 30, 2009) and a subcontract between HydroMentia and the University of Florida (Contract 08/09-151UF dated September 15, 2009).

The project as so delineated within the aforementioned contracts is intended to:

1) Determine the efficacy of the ATS™ when Santa Fe River water is applied as the target influent, in terms of reduction of total nitrogen and phosphorus and associated factions of nitrogen (e.g. ammonia-N and nitrate-N) and phosphorus (e.g. ortho-phosphorus);

2) Confirm the suitability of the targeted influent to support adequate levels of productivity of the algal turf community;

[2] Note that the Santa Fe River is a large eastern tributary to the Suwannee River, and its watershed lay within the Suwannee River Basin.

3) Establish the general nature of water quality changes associated with treatment by the ATS™ and

4) Support scientific investigations of nutrient and production dynamics associated with the ATS™ in an effort to gain a greater understanding of the mechanisms involved in nutrient reduction and accordingly to identify any operational or design adjustments which could improve the rate and extent of nutrient removal.

To meet this intent, the program was designed around the installation and simultaneous operation of two identical 500 foot long, 1 foot wide aluminum Mobile Pilot Units (MPU). One of these MPUs (SF1) was to be operated by HydroMentia in a manner emulative of what would be considered normal operation. The other MPU was to be operated by the University of Florida as a research unit. This approach allows detailed investigations into the specific dynamics associated with the technology, and may provide insight into the role of the various processes involved in nutrient removal and water quality changes, i.e. hydraulic loading, nitrogen fixation, phosphorus precipitation, and diurnal shifts in process dynamics.

The general layout of a typical MPU is as shown in Figure 1. The two parallel MPUs designed and installed for the Santa Fe River Algal Turf Scrubber® (ATS™) Pilot Project by HydroMentia (see Illustrations 1 and 2), are identical, being 500 feet long and 1 foot wide, set from south to north at a 1% slope. The site selected is in Alachua County; about 10 miles north of the City of Alachua, within the proximity of the Santa Fe River, on acreage owned by the University of Florida, for use by their Institute of Food and Agricultural Sciences (IFAS) (see Illustration 3). The Santa Fe River at this point meanders approximately 22 more miles before intersecting with the larger Suwannee River to the west.

The selected site offered some formidable engineering challenges, the most evident of which was the requirement for a long (500+ feet) intake (suction) pipe, and assuring the system would retain operability during the frequent flooding, which required the two self priming centrifugal pumps be placed upon a floating dock assembly to prevent their submergence. In addition, the force main system was over ¼ of a mile in length, with portions of it set above ground.

The long suction line was necessary to transverse the extensive hardwood wetland associated with the river flood plain with above ground piping, and to bring the flow to the electrical utilities required for pump operation. It took several adjustments before the suction line was fully operational. Two electric powered (120V/1 Phase) self priming centrifugal pumps were used to deliver flows to the MPUs, each with a capacity of about 40 gpm, at a total dynamic head (TDH) of about 30 feet. A return line was installed which allowed adjustment of flow rate delivered to the MPU. The force main piping was set such that the flows could be combined or delivered separately.

By February 2010, system operation was initiated. Flows were combined and measured using a 4" magnetic flow meter. At the individual units, the combined flow was split such that flows delivered to each unit were identical. Flow rate to each unit was set at about 20 gpm.

The start-up date for sample collection and analysis was set as February 16, 2010. Composite sampling was done at the influent and effluent using time sequenced SIGMA 900 Max autosamplers. At the influent only one sample was taken, as the MPUs received the same water at the same rate. A sampler was placed on the effluent of each MPU. Towards the end of Q1, some revisions were made at the effluent box to enhance the efficiency of removing sloughed solids prior to sample collection. For a full scale system solids removal would typically be provided by an automatic flex-rake prior to sampling.

The MPU is composed of a sloped floway constructed of aluminum, lined with a geosynthetic liner and overlain with a grid matrix. At an influent rate of approximately 20 gpm, the unit will facilitate shallow laminar flow at velocities at or close to 1 fps. The hydraulic detention period is about 10-15 minutes, during which an algal turf community attached to the floway grid extracts nutrients from the overlying water, thereby reducing nutrient concentrations. The system operation requires flow regulation and periodic removal (harvesting) of excess algal turf, which ensures the biological community remains viable and effective.

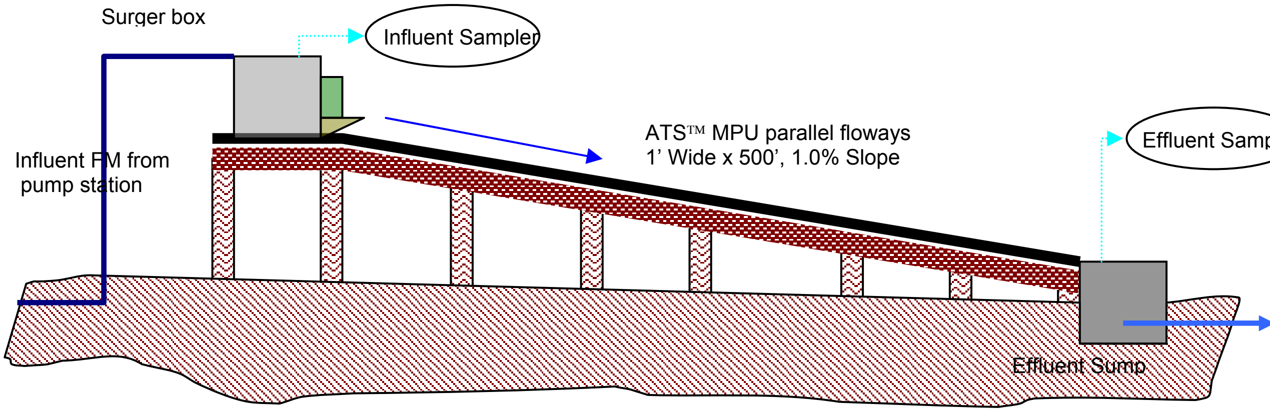


Figure 1. Schematic of Typical Pilot-Scale ATS™ System. (Not to Scale)

Illustration 1: Santa Fe River ATS™ Pilot MPUs at Surger Boxes

Illustration 2: Santa Fe River ATS™ Pilot MPUs Parallel Floways

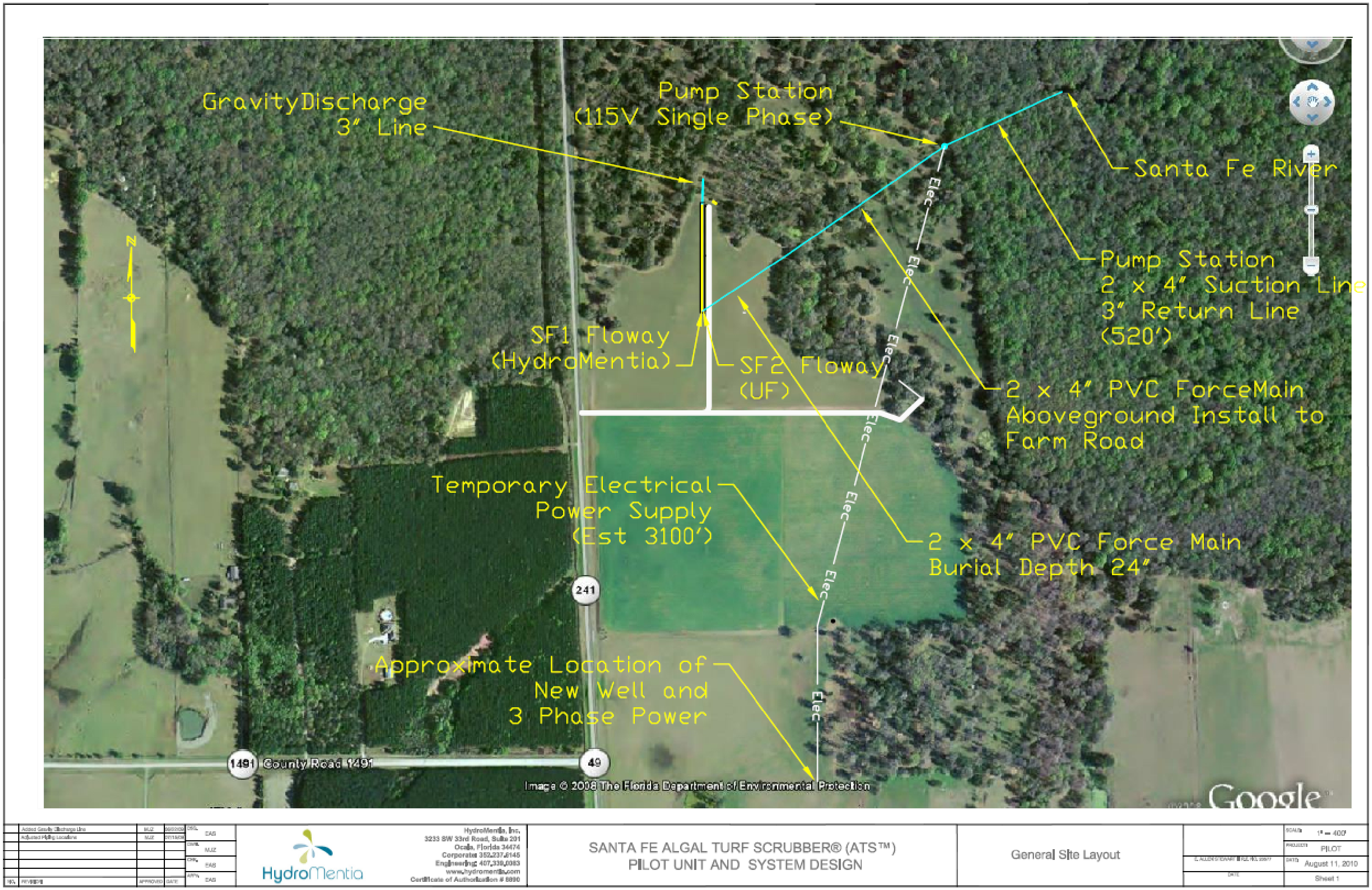


Illustration 3: General Site Layout Santa Fe ATS™ Pilot Program (Schematic Not to Scale)

Monitoring Period / Period of Record

Data reported within this text and the corresponding data collection periods are as follows:

Quarter	Monitoring Period	Length (Days)
Q1	February 16, 2010 to May 17, 2010	90
Q2	May 18, 2010 to August 17, 2010	91
Q3	August 18, 2010 to November 16, 2010	91
Q4	November 17, 2010 to December 21, 2010 and January 1, 2011 to February 22, 2011. System shut down for 21 days from December 21, 2010 to January 11, 2011 because of low levels in Santa Fe River	77
	TOTAL OPERATIONAL DAYS	349

During the initial weeks of Q1 the system was considered to be in a Start-Up and Stabilization Phase for the algal turf community. By the beginning of Q2 and through Q4, the systems' productivity, community composition and performance appeared to be stabilizing. The system will be defined as fully operational based on the definition provided below.

System Start-Up

When operation of an Algal Turf Scrubber® system is initiated, some time is required for development of a viable algal turf. During this development period, system performance is dependent on the establishment of this developing biomass.

For the Algal Turf Scrubber®, definitions that distinguish the Start-up & Stabilization Phase from the Fully Operational Phase are provided below.

Algal Turf Scrubber® Operational Phases:

(1) <u>Start-up and Stabilization Phase:</u> *System start-up is initiated with the introduction of continuous flow to the Algal Turf Scrubber® Floway. During the start-up phase, an initial algal turf community is established on the floway. During the stabilization phase, the start-up algal turf community proceeds through ecological succession toward a sustained algal turf community.*

The system operator shall define the stabilization phase complete and the system as fully operational when the following conditions are met:

a. A sustained algal turf community is present over 90% of the floway surface area

b. A sustained algal turf is established and maintained for a minimum period of 120 days with (i) minimal variation of the dominant algal turf species and (ii) minimal changes in algal productivity; except those changes that are consistent with changes in inflow water quality and ambient conditions

(2) <u>Fully Operational Phase:</u> *Algal Turf Scrubber® system is fully operational when a sustained algal turf community is established and maintained in conjunction with routine biomass recovery on the floway. Algal turf of the fully-operational phase is a complex community of algae, bacteria, diatoms and micro and macro invertebrates and detritus. Predominant attached algae species for the sustained algal turf will vary dependent on water quality, season and geographical location.*

The algal turf community is developed from fragments of periphytic algae found within the source water. During the Start-up and Stabilization Phase, the algal turf community goes through natural succession like other ecological communities. During the Stabilization Phase the treatment periphytic/epiphytic algal based community (algal turf) will be maturing and system performance will generally be improving.

As noted in other Algal Turf Scrubber® start-ups, the first evidence of algae growth is typically flocculent, dispersed groups of algae dominated by diatoms, which appear as brown to brownish-green accumulations. As ecological succession proceeds, filamentous algae - typically green algae and, in some cases, filamentous diatoms - begin to appear, and eventually become visibly predominant, forming a base of a more diverse community, that includes epiphytic diatoms, blue-green bacteria and unicellular green algae, as well a full compliment of bacterial and fungal commensals and symbiotes, and invertebrate grazers, detritivores and predators.

Duration of the Start-up and Stabilization Phase is difficult to predict, and the duration will vary according to water quality and ambient environmental conditions that include solar radiation, water temperature, hydraulic loading rates and nutrient concentration, etc.

This start-up and stabilization period is similar to other autotrophic water treatment systems, where optimal performance is achieved only after the initial start-up and stabilization phases[3]. As noted by the SFWMD and FDEP, it is anticipated that the treatment vegetation in a treatment wetland will require one to three years after flow-through operations begin for the affected cells to achieve optimal performance; and overall performance of the treatment wetland system is extremely difficult to evaluate and predict during the start-up and stabilization period. While the start-up and stabilization period for the ATS™ is of shorter duration than a treatment wetland, performance during the initial 12 months of operation should be considered a conservative estimate of treatment potential for the Algal Turf Scrubber® system.

As the standing crop of attached algae increases it can be expected to reach a biomass density at which productivity and nutrient uptake rates are optimized. The Algal Turf Scrubber® may enter a post initial system start-up Stabilization Phase after the following events: (1) system shut-down and dry-out in conjunction with loss of system flow; (2) system shut-down and algal die-off in conjunction with freezing temperatures; (3) planned/unplanned maintenance activities which result in die-off of the algal turf; or (4) algal die-off due to the presence of toxins in the source water. Duration of the stabilization phase following these events is typically shorter than the initial start-up and stabilization phase.

To assess if changes in algal biomass are consistent with changes in inflow water quality and ambient conditions per Item (1)(b) above, it is beneficial to consider changes in net community productivity relative to changes in key growth parameters including inflow water temperature, nitrogen concentration and phosphorus concentration. While algal turf systems are dynamic communities impacted by many variables, changes in net community productivity will typically be correlated with changes in water temperature and nutrient concentrations in fully operational systems.

As illustrated below, during Q3 net community productivity remained stable in Floway SF1 and increased in Floway SF2 from Q2, even though inflow water temperature, nitrogen concentration and phosphorus concentration all decreased. This increase in productivity is counter to expected changes in productivity with decreasing temperatures and nutrient levels, and indicates that the algal turf community remained in a Start-up and Stabilization Phase. In comparison, during Q4 low water temperatures, low nitrogen levels, and low river levels influenced system performance, and algal turf productivity and nutrient reduction rates were the lowest of the project term. This response is consistent with expected impacts of these factors upon biological growth dynamics indicating the system may have achieved the Fully Operational Phase.

[3] 2008. Florida Department of Environmental Protection and South Florida Water Management District. Fact Sheet for FDEP Industrial Wastewater Permit No. F10300195

	Q1	Q2	Q3	Q4
Inflow Water Temperature		▲▲[1]	▼▼	▼▼
Inflow Nitrogen Concentration		▲▲	▼▼	▼▼
Inflow Phosphorus Concentration		▲▲	▼▼	▬▬
Net Community Productivity[2]		▲▼	▬▲	▼▼

[1] Floway 1 trends illustrated via symbol on left, Floway 2 trends illustrated by symbol on right.

Illustration 4: Quarterly Trends for Algal Productivity, Inflow Water Temperature, Nitrogen Concentration and Phosphorus Concentration

SECTION 2. OPERATIONAL DATA AND ASSESSMENT

Flow

On February 16, 2010, as noted previously, monitoring of influent flow and the influent and effluent water quality were initiated for purposes of documenting system performance. Flows continued until December 21, 2010, when the water levels within the Santa Fe River fell, and surface water was made unavailable to the pumping intake. This condition remained for a period of about 21 days. Flows were continued on January 11, 2011, and were sustained until the last day of the project on February 22, 2011. Influent flows during Q4-2010 amounted to approximately 1.82 million gallons at an average flow rate of 16.4 gpm, which is lower than the other three quarters because of the mentioned low river levels and eventual temporary shut down during late December, 2010. Q3 influent flows amounted to approximately 2.48 million gallons at an average flow rate of 18.9 gpm, which is similar to the Q2 flow of 2.56 million gallons, at an average weekly flow rate per floway of 19.5 gpm, and the Q1 flow of 2.39 million gallons of water, at an average weekly flow rate per floway of 18.3 gpm. Adjustments for effluent flow were made by adding the difference between rainfall and evaporation. Rainfall was registered by the University of Florida at a nearby station. Evaporation losses were estimated from pan evaporation rates for Central Florida[4]. Flow patterns for the first three quarters are noted in Figures 2 and 3.

Algal Turf Productivity

Prior to initiation of monitoring on February 13, 2010, both floways (SF1 which is managed by HydroMentia, and SF2 which is managed by UF) received intermittent flows as a result of efforts to establish a reliable influent pumping arrangement. Consequently, some algal turf had developed on both floways prior to program initiation, although this development was more pronounced on SF2, as flow delivered to this floway was somewhat more reliable during the interim period. During the first quarter flows were sustained without interruption, except for a period during the week ending 5/11/10. This loss of flow was due to a power loss, because of a "tripped" breaker. Because of the extended power loss during the week of 5/11/10, the algal turf was lost on both floways, but recovered in the following weeks. This issue was resolved, and flow remained uninterrupted until the purposeful shutdown from December 21, 2010 to January 11,2011 because of low levels in the Santa Fe River. During the weeks ending 10/31/10 and 9/7/10 of Q3 and weeks ending 12/14/10, 12/21/11 and 11/18/11 of Q4 reduced flows were noted because of lower levels in the Santa Fe River.

At project initiation, SF2, as noted, showed heavier algal turf growth. As mentioned, this may have been attributable to the fact that SF2 had received more consistent flow during the weeks before program initiation. As is typical for the start-up and stabilization phase, initial algal turf growth was dominated by diatoms, including filamentous types such as *Melosira.* The first harvest was conducted on 3/2/10 on SF2, and on 3/16/10 on SF1. Following these first harvests, the algal turf shifted gradually toward filamentous green algae, such as*, Rhizoclonium sp. and Spirogyra sp.*

By the end of Q1 the turf development appeared similar on both floways. Through most of Q2, appearance and production of the algal turf remained similar on both floways, although some variation was noted after the surging of flows to SF2 was terminated on 7/20/10—as discussed within a later section. Through Q3, both floways showed similar growth patterns, with the green filamentous algae *Cladophora sp* showing dominance along the first 250 feet of the floway, with some *Cyanobacteria* (blue-green) algae noted early in the quarter, and the filamentous diatom *Melosira sp.* noted along the final 250 feet of the floway. During Q4, lower temperatures and lower nitrogen levels, as well as lower flow rates, may have contributed to the observed lower levels of productivity. The algal turf during Q4 was

[4] Schiffer, Donna M. 1997. Hydrology of Central Florida Lakes—A Primer. USGS Circular 1137 in cooperation with the St. Johns River Water Management District. ISBN 0-607-88561-0

represented largely by the filamentous diatom *Melosira sp.*, with a few filaments of green algae noted in November, with *Cyanobacteria* becoming dominant during the final two weeks of operation.

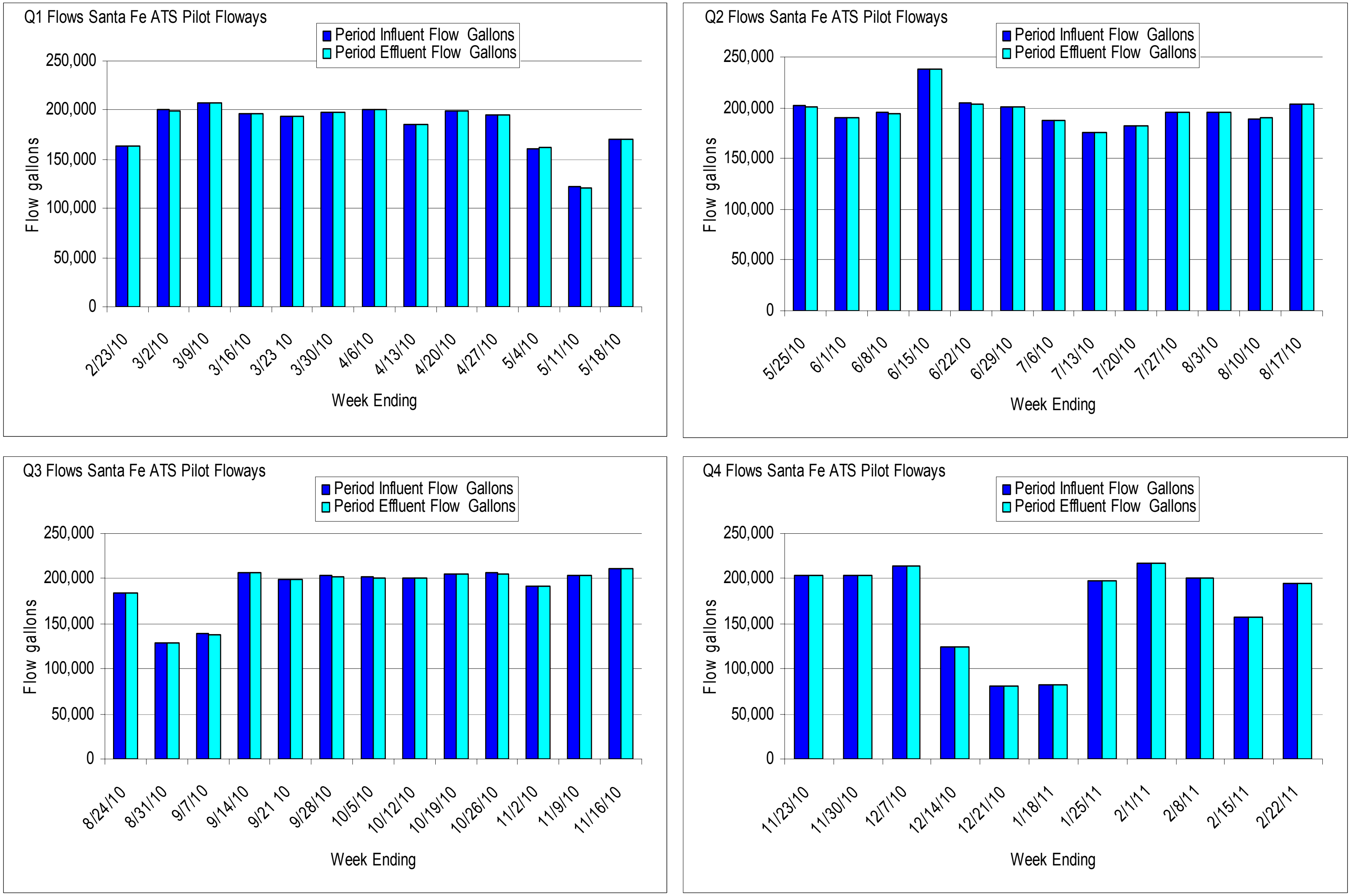


Figure 2. Flow Volumes for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

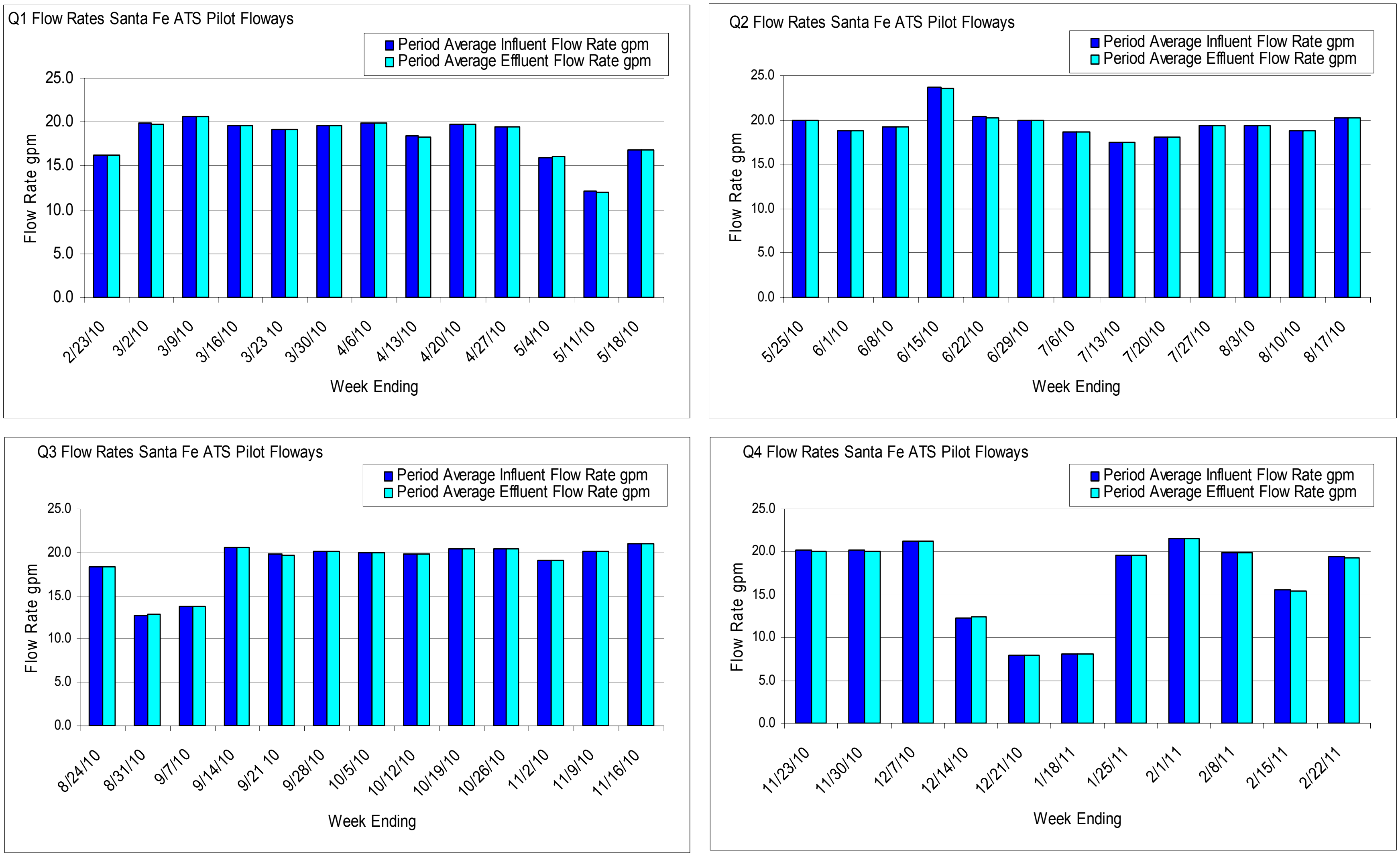


Figure 3. Flow Rates for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

On 6/1/10 of Q2, both floways showed complete loss of the algal turf. During that week glyphosate was sprayed on nearby fields. Glyphosate is a herbicide known to be lethal to algae, and it is suspected, although not conclusively shown, that this may have caused the crop loss. Based on data recorded at the nearby University of Florida weather station, wind direction during application of the glyphosate was not in the direction of the ATS™ floway. During the following three weeks the systems showed recovery, with the filamentous green algae *Cladophora sp.* showing predominance. On 6/29/10 the system was harvested, and both floways showed comparatively high levels of production.

On 7/20/10 it was decided to stop the surging on floway SF2, thereby facilitating assessment of the impacts of surge upon system performance and algae production. By the end of Q2, it was noted that the floway with surge (SF1) was showing somewhat higher levels of production, with the turf composed of a mix of filamentous green and blue green algae. Floway SF2 showed a lower rate of development of filamentous green algae, less blue green algae, and a relative abundance of filamentous diatoms. The surge was restarted on 8/17/10. After the surge was restarted the two floways again showed similar development patterns, with a notable paucity of production along the final reaches of the floways, which is typically indicative of some type of nutrient limitation - quite possible nitrogen or carbon in this case. Harvesting of the turf was conducted on the dates noted below.

Q1	Q2	Q3	Q4
March 2, 2010 (SF2 only)	May 25, 2010	September 14, 2010	November 30, 2010
March 30, 2010	June 29, 2010	September 28, 2010	February 8, 2011
April 6, 2010	July 20, 2010	October 12, 2010	
April 13, 2010	August 3, 2010	November 2, 2010	
April 20, 2010	August 17, 2010		
April 27, 2010			
May 4, 2010			

The comparative harvests for Q1 through Q4, as noted in Table 1 and Figure 4, show that during Q1, dry weight production for SF2 surpassed that for SF1, although this is reversed for Q2. During Q3 and Q4, production levels were similar for both floways, and for the combined quarters, the two floways show comparatively similar harvest amounts (Figure 5).

Table 1: Comparative Harvest Weights Q1 through Q4

Floway	Q1 Wet Harvest (lbs)	Q2 Wet Harvest (lbs)	Q3 Wet Harvest (lbs)	Q4 Wet Harvest (lbs)	Total Project Wet Harvest (lbs)	Q1 Dry Harvest (lbs)	Q2 Dry Harvest (lbs)	Q3 Dry Harvest (lbs)	Q4 Dry Harvest (lbs)	Total Project Dry Harvest (lbs)
SF1(HMI)	392	986	817	253	2,478	27	61	45	11	144
SF2 (UF)	1,156	763	650	199	2,768	52	49	48	11	160

Productivity for the algal turf community is calculated as the product of the wet harvest weight and percent dry solids divided by the days between harvest and the surface area of the floway. This value, expressed as dry-g/m^2-day, is an approximation of net community productivity, and includes the summation of accumulated biomass and associated residuals from all involved trophic levels. It should not be confused with net primary production, or gross productivity, which relate only to productivity of the photoautotrophic (and in some cases chemoautotrophic) organisms.

When the nutrient content of the harvested biomass is determined, then the mass recovery of nitrogen and phosphorus from harvest can be determined. The nutrients recovered by harvest are often lower than the removal as calculated from changes in water nutrient concentrations (influent – effluent), as the harvest quantity does not include emigration losses such as would be associated with the hatching of flying insect pupae (e.g. Dipterans such as Chironomids), predation or grazing from visiting animals (e.g. birds), and losses associated with algal sloughing.[5]

For Q1, calculated dry harvests and net community productivity were notably higher for SF2 (52 pounds dry harvest and 7.29 dry-g/m^2-day) than for SF1 (27 pounds dry harvest and 3.82 dry-g/m^2-day). As mentioned, this could be a result of the higher initial standing crop associated with SF2.

During Q2, this trend was reversed, with SF1 (61 pounds dry harvest and 5.67 dry-g/m^2-day) showing a higher productivity than SF2 (49 pounds dry harvest and 4.51 dry-g/m^2-day). During Q3 the two floways showed similar net community productivity, with SF1 at 45 pounds dry harvest and 5.67 dry-g/m^2-day net community productivity, and SF2 at 49 pounds dry harvest and 6.02 dry-g/m^2-day net community productivity. For Q4 the two floways were also similar, with productivity being considerably lower than previous quarters, at 11 pounds dry harvest and 1.85 dry-g/m^2-day net community productivity for SF1, and 11 pounds dry harvest and 1.92 dry-g/m^2-day net community productivity for SF2. For the combined Q1 through Q4 monitoring period the two systems' net community productivity were also comparatively similar—SF1 at 4.57 dry-g/m^2-day and SF2 at 5.04 dry-g/m^2-day. The perceived higher production of SF1 during Q2 may be partly attributable to the lack of surge on SF2, although the difference was not found to be statistically distinct at the 95% confidence level. Weekly harvests and productivity for Q1 through Q4, which show these trends, are noted in Figures 5 through 7.

One trend was noted regarding productivity related to the comparative dry harvest per 100 foot sections of the flow. During Q1 the growth was rather evenly distributed along the floway, while during Q2 and Q3 high growth patterns were much more prevalent in the first 200 feet, decreasing noticeably in most cases from 200-500 ft, as seen in Figures 8 and 9. This may be associated with a paucity of carbon, as the alkalinity is quite low within the influent water, although available nitrogen may also be limiting in some cases. During Q2 and continuing through Q3, while alkalinity was about the same as Q1, the influent pH increased from about 6.63 for Q1 to 7.22 for Q2 to 7.39 for Q3, meaning the available carbon was reduced considerably. During Q4, productivity was notably lower than the other quarters, largely because of cooler temperatures, but perhaps as well to lower nitrogen levels.

There is not enough data to conclusively support these suppositions, but they appear reasonable. Of course many factors can impact both production and the relative rate of production down the floway length, including grazing pressure; enzymatic activity upon recalcitrant nitrogen and phosphorus compounds; pH and temperature changes; attenuation of inhibiting factors; and nitrogen fixation. System production and performance at various stages down the floway provides insight into understanding system dynamics and for determining the most cost effective floway length.

Specific Net Community Growth Rates, Tissue Quality and Standing Crop Estimates

Specific net community growth rates were calculated as $[\ln(Z_t/ Z_0)]/t$, where Z_t is the dry standing crop at the time of harvest, Z_0 is the initial dry standing crop, and t is the time between harvests in hours.

The initial standing crop Z_0 is estimated as 10 percent of the total standing crop at time of the previous harvest (i.e. harvesting removes 90% of the total standing crop) and is calculated as dry harvest of the previous period x 0.11. Calculated growth rates for Q1 and Q2 for the two floways are similar, if the 90% harvest approximation is applied (Figure 10). The implication is that the energy dynamics of the two systems may be similar, and that as the turf matures and stabilizes, productivity patterns can be expected to converge.

It is noted that the specific growth rate over the entire floway length decreased considerably during Q2, and remained comparatively low during Q3 as compared to Q1, and fell even further during Q4 (Figure

[5] Sloughing losses can be substantial during pilot investigations because the harvest methods do not facilitate recovery of very fine solids, which escape as drainage.

10).This is a trend that would be expected when frequency of harvest is decreased, and density stresses upon the community impose upon specific growth rate, or when nutrient limitations or temperature impacts become influential. However, with increased average standing crop and density of the initial standing crop, production may, but does not necessarily decline with a lower specific growth rate, and as noted can be particularly high in the upstream reaches of the floway (see Figures 8 and 9). For example, as noted in Figure 11, productivity, particularly in SF1, increased considerably during the time when the specific growth rate declined during Q2. This means that the operational goal is not so much to drive the system to the highest specific growth rate, but rather to higher levels of production, as typically the higher the productivity the greater the rate of nutrient reduction.

The average standing crop (Z_{ave}) for any harvest period (time between harvests), therefore becomes an important component regarding system predictability and optimization. The operational question therefore is what is the highest average standing crop which yields the greatest productivity, and will most likely yield the greatest rate of nutrient removal? The average standing crop can be calculated by:

$$\mathbf{Z_{ave}} = \left(\sum_{t=0}^{t=n} \mathbf{Z_t} e^{24\mu} \right) / n$$

Where $\mathbf{Z_{t=0}}$ is the initial standing crop, **μ** is the net community specific growth rate as 1/hr, and t is time in days since previous harvest.

It is desirable to maintain as high a standing crop as possible, without deterioration of turf viability, and subsequent collapse of net community productivity. The estimated average standing crops, (based on the assumption that 10% of final standing crop remains as the initial standing crop for the next harvest period), for Q1 are comparatively low, averaging 19.21 dry g/m^2 for SF1 and 30.42 dry g/m^2 for SF2. The average standing crop increased during Q2 on both floways, but most dramatically for SF1. The average standing crop for SF1 during Q2 was 51.46 dry g/m^2 and for SF2 41.24dry g/m^2. During Q3 the average standing crop was similar for both floways at 47.59 dry g/m^2 for SF1 and for SF2, 53.56dry g/m^2. For Q4 the average standing crop decreased to 30.21 dry g/m^2 for SF1 and 25.84 dry g/m^2 for SF1 For the combined Q1 through Q4 monitoring period, average standing crops for the two floways were similar, being 37.79 dry g/m^2 for SF1 and 39.94 dry g/m^2 for SF2 (Table 2).

Tissue quality in terms of nutrient and mineral content was examined in composite samples taken every 100 feet down for both floways by HydroMentia in March 2010. For May 2010 HydroMentia collected samples for SF1 only at 100 foot intervals. The University of Florida is conducting more detailed tissue review of SF2. This SF2 data from UF was not available for this report. In June 2010, a composite sample for both SF1 and SF2 were taken by HydroMentia as one composited sample for the entire floway. In July 2010, HydroMentia took composited floway samples just for SF1, while samples were taken for both SF1 and SF2 in August 2010 through December 2010.

It is noteworthy that there is not a distinctly discernible trend in tissue quality down the floway, per the March and May data. This is counter to what has been typically observed in other pilot systems, where there has been noted a decline in tissue nutrient levels from influent to effluent ends of the floway. In fact within SF1 if any trend is noted, it is an increase in nutrient tissue levels from influent to effluent. While certainly not conclusive, the implication is that changes occur down the floway that encourage enhanced nutrient uptake. Such changes could relate to temperature or pH shifts, attenuation of inhibiting influences, enzymatic conversion of recalcitrant compounds rendering them biologically available, or other phenomenon such as nitrogen fixation.

Tissue analyses for March and May are summarized in Tables 3 and 4 for the 100 foot floway intervals. A summary of average composited tissue quality for March through July is shown in Table 5, for August through November in Table 6, and December/January in Table 7. Noted as Figures 12 and 13 are trends related to nitrogen and phosphorus tissue content from March through December. From August through

November both the nitrogen and phosphorus content of SF2 appears consistently lower than SF1, and is particularly noted with phosphorus.

A comparison of nutrient tissue content and influent water quality as shown in Figures 14 and 15, shows only weak correlations, indicating that factors other than nutrient levels within the influent water likely influence tissue nutrient levels. Carbon availability is quite possible involved in determining tissue nutrient levels. Another factor could be the flow surging, as the August tissue data indicates a lower quality tissue in the non-surging SF2 floway. A review of the impacts of surging is included in a later section of this text.

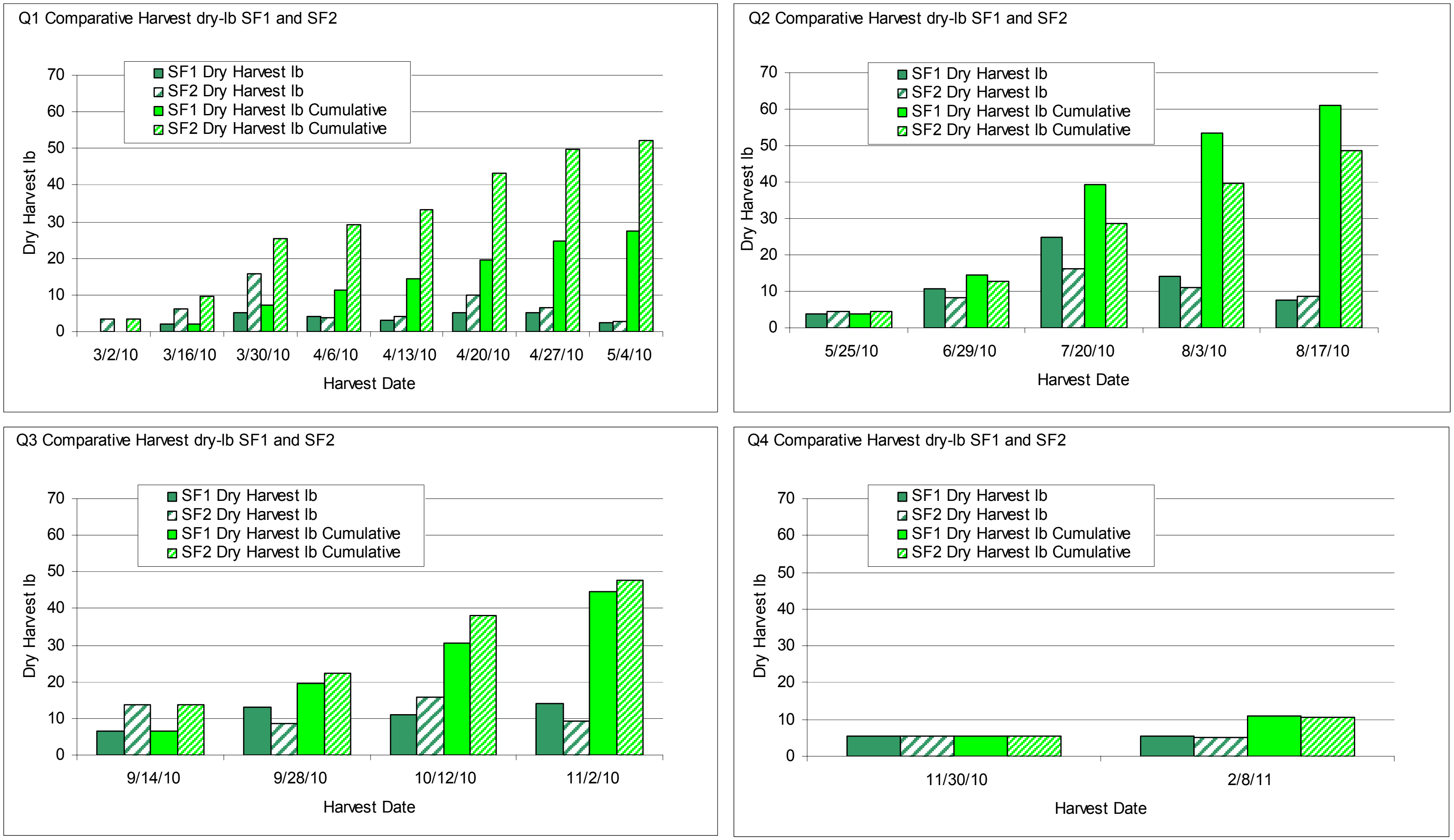


Figure 4. Dry Harvest for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

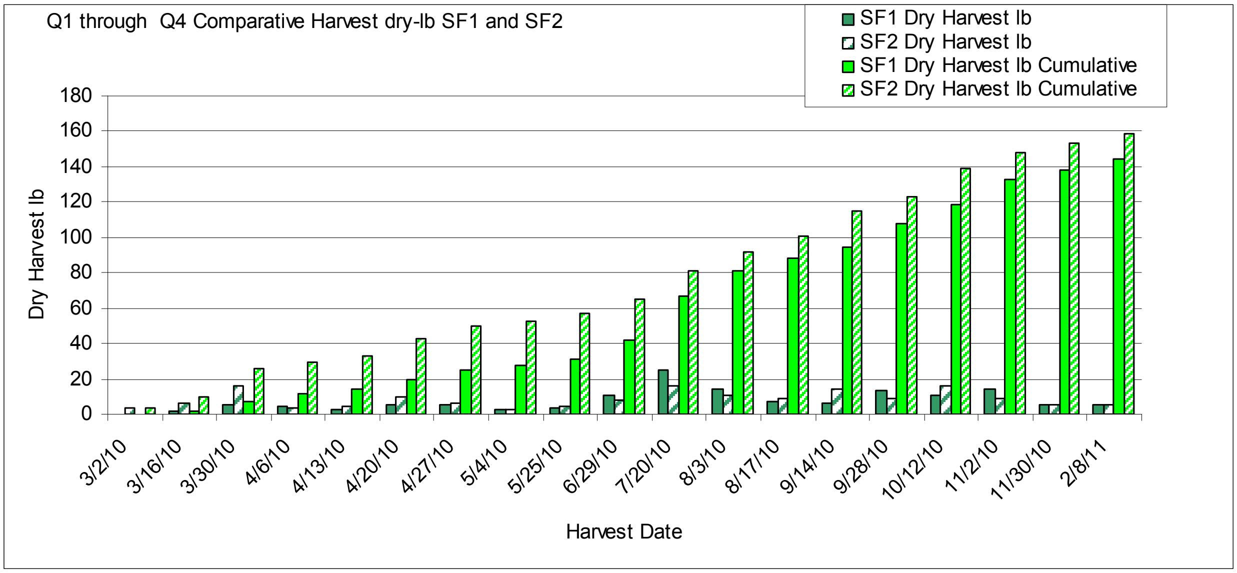
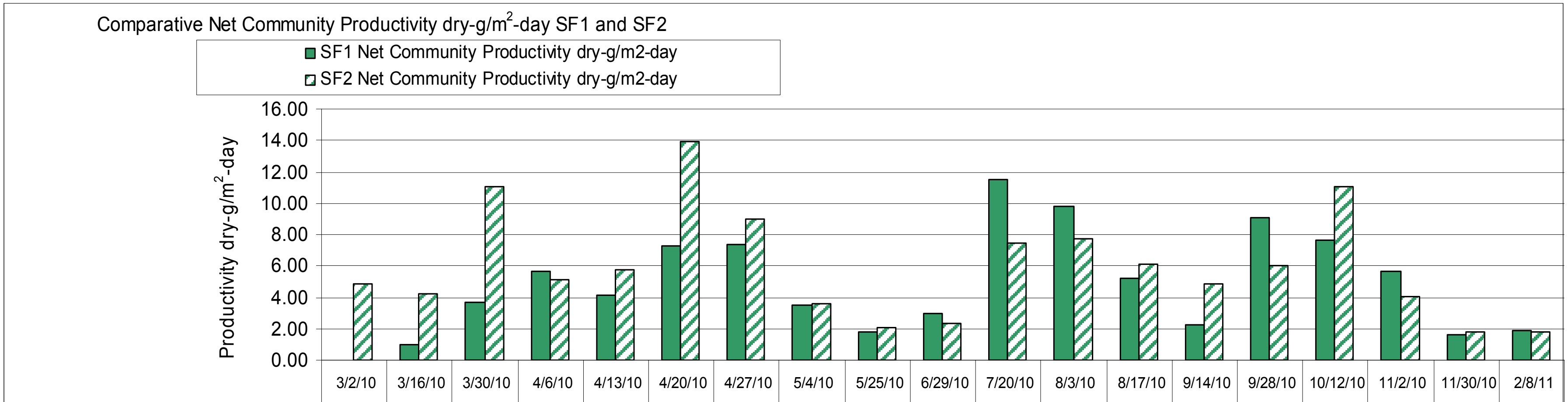


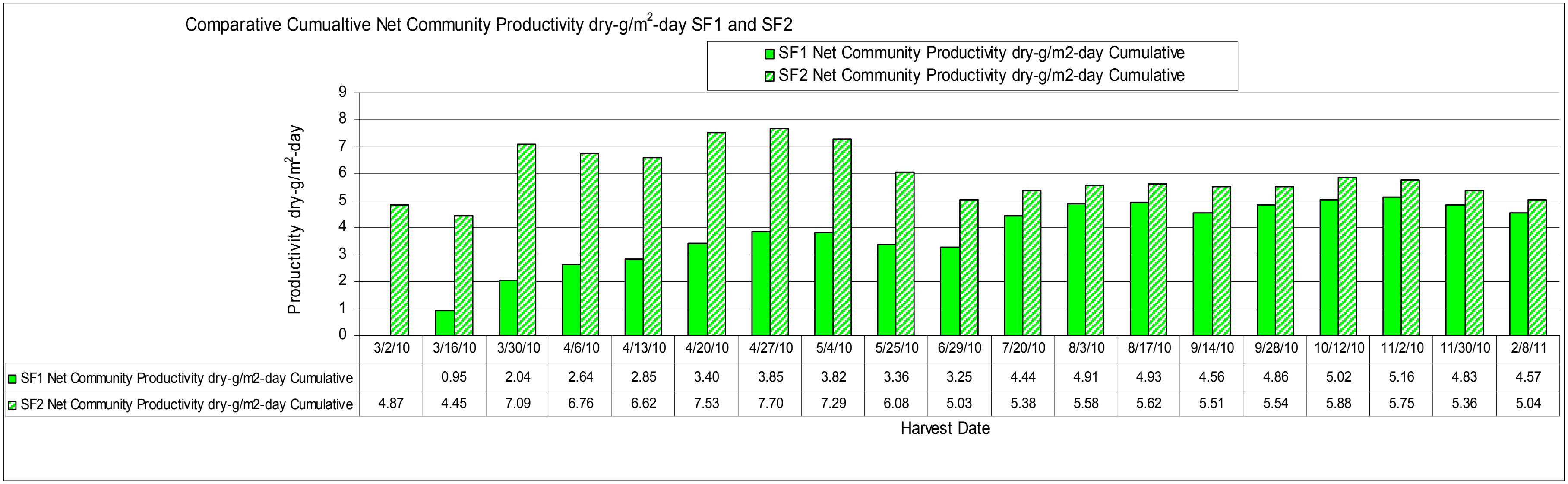
Figure 5. Cumulative Dry Harvest for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program



	3/2/10	3/16/10	3/30/10	4/6/10	4/13/10	4/20/10	4/27/10	5/4/10	5/25/10	6/29/10	7/20/10	8/3/10	8/17/10	9/14/10	9/28/10	10/12/10	11/2/10	11/30/10	2/8/11
SF1 Net Community Productivity dry-g/m2-day		0.95	3.69	5.64	4.10	7.27	7.41	3.53	1.83	2.98	11.55	9.81	5.19	2.28	9.11	7.60	5.67	1.60	1.91
SF2 Net Community Productivity dry-g/m2-day	4.87	4.25	11.05	5.11	5.79	13.90	9.00	3.62	2.03	2.32	7.48	7.70	6.07	4.83	6.00	11.04	4.01	1.75	1.80

Harvest Date

Figure 6. Algal Turf Productivity (Net Community Productivity) per Harvest Event for Floways SF1 and SF2 for Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program



	3/2/10	3/16/10	3/30/10	4/6/10	4/13/10	4/20/10	4/27/10	5/4/10	5/25/10	6/29/10	7/20/10	8/3/10	8/17/10	9/14/10	9/28/10	10/12/10	11/2/10	11/30/10	2/8/11
SF1 Net Community Productivity dry-g/m2-day Cumulative		0.95	2.04	2.64	2.85	3.40	3.85	3.82	3.36	3.25	4.44	4.91	4.93	4.56	4.86	5.02	5.16	4.83	4.57
SF2 Net Community Productivity dry-g/m2-day Cumulative	4.87	4.45	7.09	6.76	6.62	7.53	7.70	7.29	6.08	5.03	5.38	5.58	5.62	5.51	5.54	5.88	5.75	5.36	5.04

Figure 7. Cumulative Algal Turf Productivity (Net Community Productivity) per Harvest Event for Floways SF1 and SF2 for Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

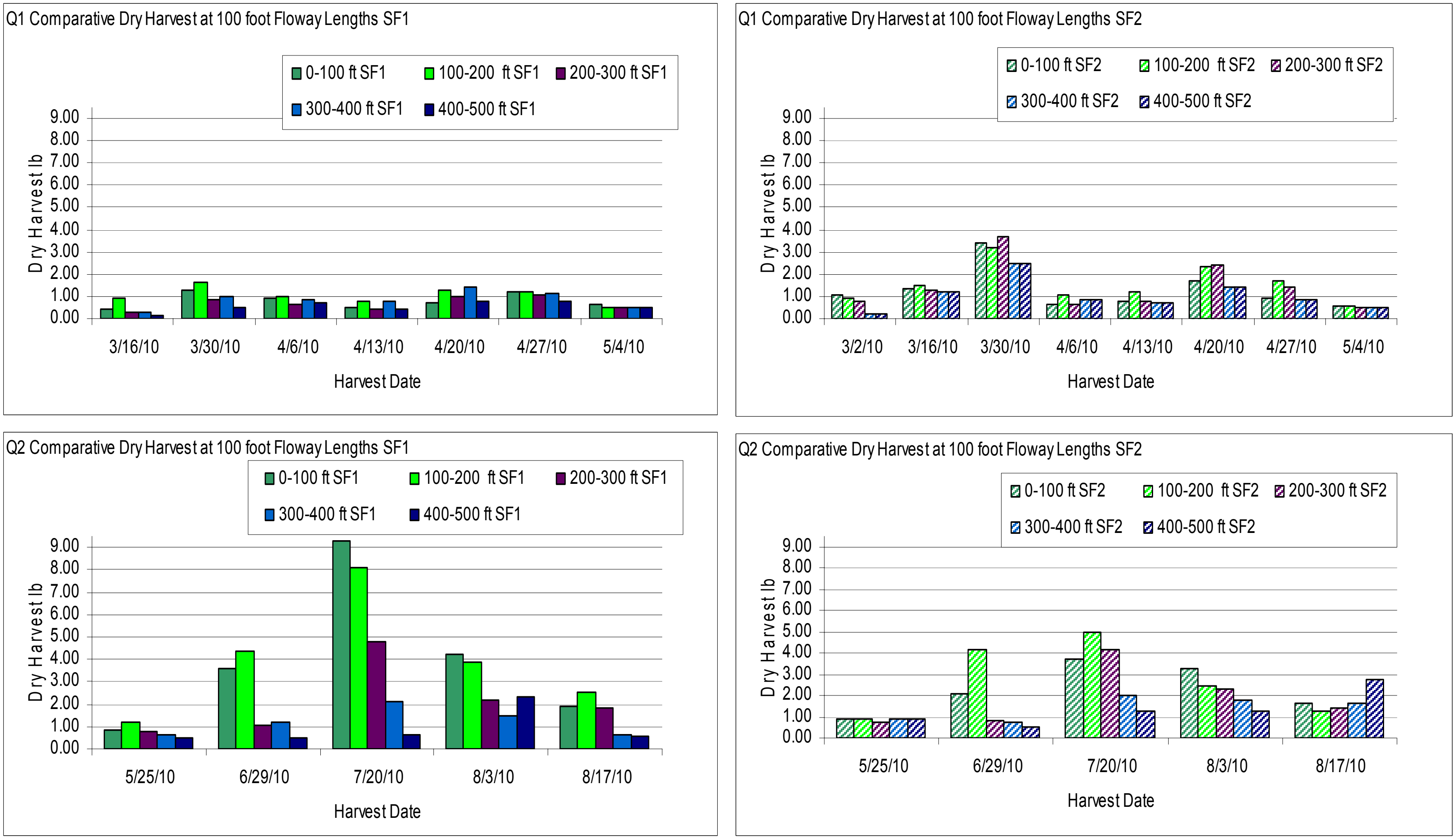


Figure 8. Comparative Algal Turf Dry Harvest at Various Lengths Down the Floways SF1 and SF2 for Q1 through Q2 Monitoring Period - Santa Fe ATS™ Pilot Program

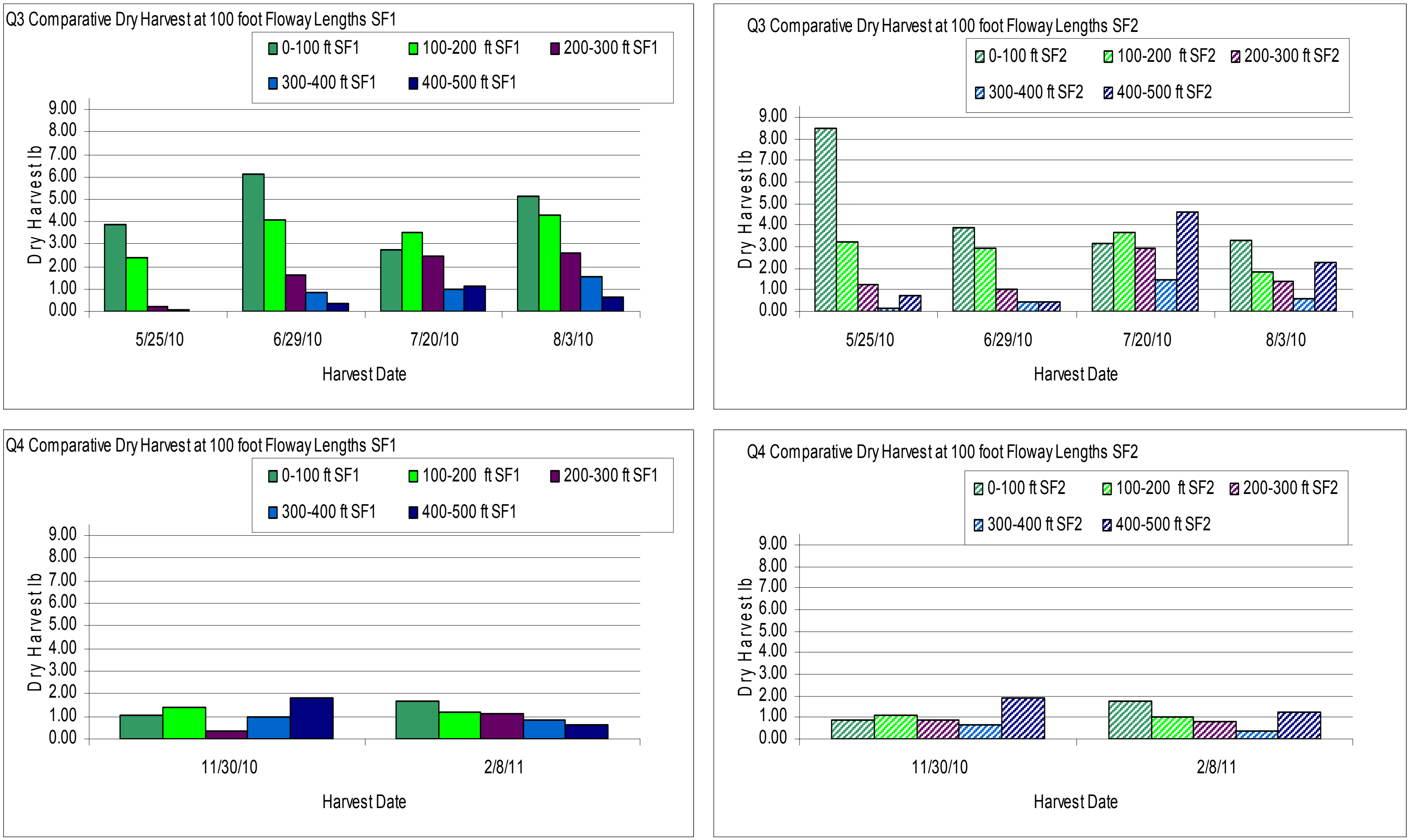
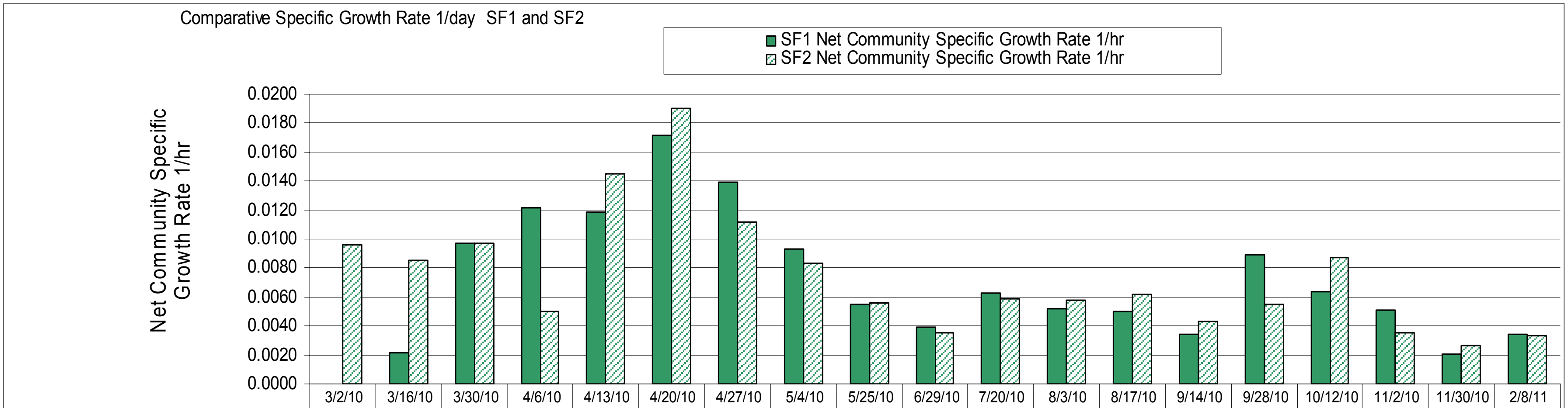


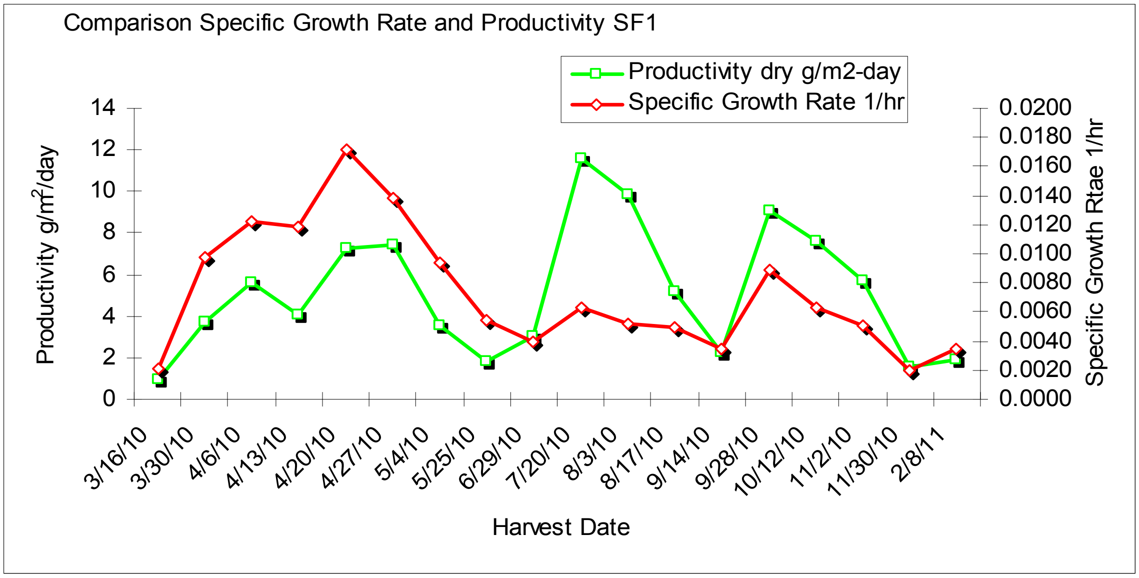
Figure 9. Comparative Algal Turf Dry Harvest at Various Lengths Down the Floways SF1 and SF2 for Q3 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program



	3/2/10	3/16/10	3/30/10	4/6/10	4/13/10	4/20/10	4/27/10	5/4/10	5/25/10	6/29/10	7/20/10	8/3/10	8/17/10	9/14/10	9/28/10	10/12/10	11/2/10	11/30/10	2/8/11
SF1 Net Community Specific Grow th Rate 1/hr		0.0021	0.0097	0.0122	0.0119	0.0172	0.0139	0.0093	0.0055	0.0039	0.0063	0.0052	0.0050	0.0034	0.0089	0.0063	0.0051	0.0020	0.0034
SF2 Net Community Specific Grow th Rate 1/hr	0.0096	0.0085	0.0097	0.0050	0.0145	0.0190	0.0112	0.0084	0.0056	0.0035	0.0059	0.0058	0.0062	0.0043	0.0055	0.0087	0.0035	0.0026	0.0034

Harvest Date

Figure 10. Specific Growth Rate for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program



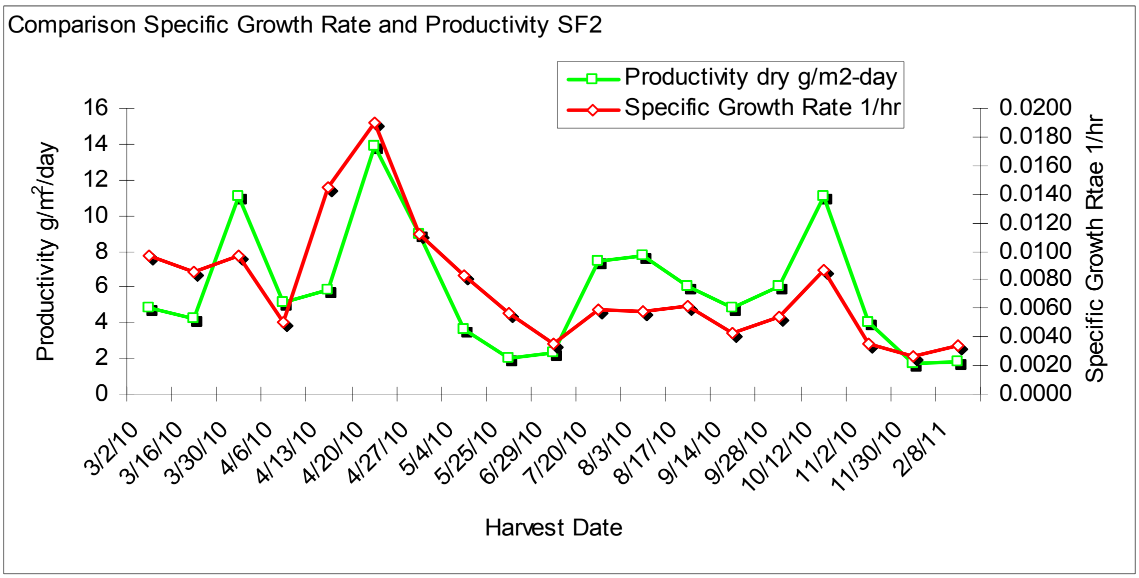


Figure 11. Algal Turf Specific Growth Rates and Net Community Productivity for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

Table 2: Q1 through Q4 Initial and Average Standing Crops for Floways SF1 and SF2

Date Q1	SF1 Initial Standing Crop (dry-g/m^2)	SF2 Initial Standing Crop (dry-g/m^2)	SF1 Average Standing Crop (dry-g/m^2)	SF2 Average Standing Crop (dry-g/m^2)
3/2/10	-	7.50	-	21.00
3/16/10	7.50	3.75	13.87	24.02
3/30/10	2.19	6.54	18.93	56.74
4/6/10	5.68	17.02	21.52	28.46
4/13/10	4.34	3.94	15.86	19.97
4/20/10	3.15	4.46	22.57	40.47
4/27/10	5.60	10.70	26.24	35.99
5/4/10	5.71	6.93	15.44	16.72
AVERAGE Q1	**4.88**	**9.21**	**19.21**	**30.42**
Date Q2	**SF1 Initial Standing Crop (dry-g/m^2)**	**SF2 Initial Standing Crop (dry-g/m^2)**	**SF1 Average Standing Crop (dry-g/m^2)**	**SF2 Average Standing Crop (dry-g/m^2)**
5/25/10	2.71	2.79	15.50	16.82
6/29/10	4.23	4.68	35.39	30.13
7/20/10	11.49	8.92	88.06	59.74
8/3/10	26.68	17.28	76.82	56.70
8/17/10	15.11	11.86	41.53	42.81
AVERAGE Q2	**11.28**	**9.11**	**51.46**	**41.24**
Date Q3	**SF1 Initial Standing Crop (dry-g/m2)**	**SF2 Initial Standing Crop (dry-g/m2)**	**SF1 Average Standing Crop (dry-g/m2)**	**SF2 Average Standing Crop (dry-g/m2)**
9/14/10	7.21	8.18	29.05	51.37
9/28/10	7.03	14.86	49.83	45.55
`10/12/10	14.03	9.23	52,68	61.60
11/2/10	11.70	17.00	58.81	55.73
AVERAGE Q3	**9.99**	**12.32**	**47.59**	**53.56**
Date Q4	**SF1 Initial Standing Crop (dry-g/m2)**	**SF2 Initial Standing Crop (dry-g/m2)**	**SF1 Average Standing Crop (dry-g/m2)**	**SF2 Average Standing Crop (dry-g/m2)**
11/30/10	15.50	10.02	35.38	28.55
2/8/11	5.95	5.82	25.07	23.15
AVERAGE Q4	**10.62**	**7.94**	**30.21**	**25.88**
AVERAGE Q1 through Q4	**8.64**	**9.11**	**37.39**	**39.94**

Table 3: Tissue Analysis Harvested Algal Turf Biomass for Floways SF1 and SF2 March 2010

Santa Fe ATS

SF1	Mar-10						SF2	Mar-10					
dry weight basis	0-100 ft	100-200	200-300	300-400	400-500	Average		0-100 ft	100-200	200-300	300-400	400-500	Average
N %	2.08	2.33	2.72	2.33	2.53	2.40		2.06	2.17	2.20	1.67	1.67	1.95
Ammonium N%	0.16	0.08	0.08	0.10	0.04	0.08		0.09	0.08	0.07	0.12	0.13	0.10
Nitrate N%	nd	nd	nd	nd	nd	nd		nd	nd	nd	nd	nd	nd
Organic N%	1.93	2,28	2.64	2.23	2.49	2.32		1.97	2.09	2.10	1.55	1.54	1.85
P2O5 %	0.99	1.56	1.57	1.54	1.48	1.43		1.42	1.49	1.47	1.50	1.51	1.48
P %	0.48	0.76	0.76	0.75	0.72	0.70		0.69	0.73	0.72	0.73	0.74	0.72
K2O %	0.39	0.87	0.89	1.18	1.31	0.93		0.75	0.82	0.93	1.08	1.06	0.93
S %	0.32	0.43	0.45	0.44	0.49	0.43		0.39	0.40	0.41	0.43	0.42	0.41
Ca %	0.97	1.31	1.32	1.14	1.20	1.19		1.18	1.47	1.31	1.14	1.18	1.26
Mg %	0.20	0.33	0.31	0.32	0.35	0.30		0.33	0.28	0.34	0.30	0.35	0.32
Na %	0.05	0.61	0.12	0.08	0.20	0.21		0.05	0.07	0.07	0.08	0.07	0.07
Cu ppm	38	50	33	27	nd	30		22	22	28	nd	25	19
Fe ppm	7,474	11,542	10,551	10,551	10,792	10,182		12,128	10,272	11,655	9,830	15,326	11,842
Mn ppm	2,632	3,611	2,799	2,253	1,574	2,574		3,881	2,881	2,751	2,473	2,666	2,930
Zn ppm	97.00	178.00	177.00	170.00	150.00	154.40		160	220	157	182	188	181
pH	6.70	6.70	6.80	6.80	7.00	6.80		6.60	6.70	6.80	6.70	6.70	6.70
Total Carbon %	17.98	18.48	16.28	15.32	14.42	16.50		19.05	14.87	14.74	11.01	11.86	14.31
C/N Ratio	8.6:1	7.7:1	6.1:1	6.6:1	5.7:1	7.15:1		9.3:1	6.9:1	6.8:1	6.6:1	7.1:1	7.34:1
Chloride	0.11	0.26	0.27	0.29	0.45	0.28		0.14	0.21	0.20	0.31	0.27	0.23

Table 4: Tissue Analysis Harvested Algal Turf Biomass for Floway SF1 May 2010

Santa Fe ATS SF1	May-10					
dry weight basis	0-100 ft	100-200	200-300	300-400	400-500	Average
N %	2.60	2.42	2.70	2.40	2.17	2.46
Ammonium N%	0.11	0.06	0.04	0.03	0.05	0.06
Nitrate N%	nd	nd	nd	nd	nd	nd
Organic N%	2.49	2.35	2.66	2.36	2.12	2.40
P2O5 %	1.56	1.62	1.72	1.66	1.64	1.64
P %	0.76	0.79	0.84	0.81	0.80	0.80
K2O	0.78	1.10	1.28	1.27	1.09	1.10
S ppm	0.39	0.45	0.46	0.44	0.42	0.43
Ca %	0.91	0.98	0.94	0.93	1.00	0.95
Mg %	0.30	0.34	0.34	0.37	0.37	0.34
Na %	0.04	0.12	0.07	0.10	0.07	0.08
Cu ppm	nd	nd	nd	nd	nd	nd
Fe ppm	10,946	11,657	10,001	12,038	13,584	11,645
Mn ppm	3,587	3,573	2,274	2,364	2,173	2,794
Zn ppm	92	114	108	112	112	108
pH	6.80	6.90	6.90	7.20	7.00	6.96
Total Carbon %	16.52	15.97	15.70	14.66	14.23	15.42
C/N Ratio	6.4:1	6.6:1	5.8:1	6.1:1	6.5:1	6.3:1
Chloride	0.10	0.24	0.15	0.18	0.14	0.16

Table 5: Tissue Analysis Harvested Algal Turf Biomass for Floways SF1 and SF2 March through July 2010

Parameter	**March 2010**		**May 2010**	**June 2010**		**July 2010**
(dry weight basis)	**SF1**	**SF2**	**SF1**	**SF1**	**SF2**	**SF1**
N%	2.40	1.95	2.46	4.21	3.81	1.79
Ammonium N %	0.08	0.10	0.06	0.04	0.02	0.01
Nitrate N %	nd	nd	nd	nd	nd	nd
Organic N %	2.32	1.85	2.40	4.17	3.79	1.78
P_2O_5 %	1.43	1.48	1.64	1.93	1.94	1.57
P %	0.62	0.65	0.72	0.84	0.85	0.69
K_2O %	0.93	0.93	1.10	0.86	1.04	2.50
S ppm	0.43	0.41	0.43	0.47	0.48	0.56
Ca %	1.19	1.26	0.95	1.26	1.29	2.13
Mg %	0.30	0.32	0.34	0.38	0.36	0.34
Na %	0.21	0.07	0.08	0.04	0.04	0.06
Cu ppm	30	19	nd	nd	nd	nd
Fe ppm	10,182	11,842	11,645	18,776	19,674	18,147
Mn ppm	2,574	2,930	2,794	3,604	3,103	6,738
Zn ppm	154.4	181	108	114	130	158
pH	6.8	6.70	6.96	6.20	6.40	7.70
Total Carbon %	16.5	14.31	15.42	31.15	29.16	20.24
C/N Ratio	7.15:1	7.34:1	6.3:1	7.4:1	7.7:1	11.3:1
Chloride %	0.28	0.23	0.16	0.11	0.15	0.59

Table 6: Tissue Analysis Harvested Algal Turf Biomass for Floways SF1 and SF2 August through November 2010

Parameter	August 2010		September 2010		October 2010		November 2010	
(dry weight basis)	SF1	SF2	SF1	SF2	SF1	SF2	SF1	SF2
N%	2.82	2.21	3.69	2.70	3.27	2.01	2.86	2.44
Ammonium N %	0.24	0.23	0.03	0.03	0.02	0.05	0.12	0.15
Nitrate N %	nd	nd	0.99	0.05	0.05	0.09	nd	nd
Organic N %	2.58	2.09	2.67	2.61	3.19	1.87	2.77	2.29
P_2O_5 %	1.75	1.52	1.72	1.74	1.37	1.48	1.95	1.64
P %	0.76	0.66	0.72	0.76	0.60	0.61	0.85	0.72
K_2O %	1.08	0.75	4.73	4.97	3.44	1.46	1.21	2.09
S %	0.60	0.43	0.94	0.95	0.89	0.45	0.54	0.48
Ca %	2.04	1.53	1.44	1.70	2.05	1.72	1.78	1.04
Mg %	0.43	0.43	0.32	0.41	0.36	0.31	0.32	0.37
Na %	0.07	0.07	0.08	0.11	0.14	0.06	0.07	0.10
Cu ppm	nd	nd	Nd	nd	nd	nd	nd	nd
Fe ppm	25,527	19,204	16,200	20,928	14,805	15,300	30,907	21,256
Mn ppm	5,137	4,947	7,900	12,684	5,087	6,970	29,165	14,098
Zn ppm	220	197	128	144	146	147	205	167
pH	6.30	6.60	8.00	7.30	8.40	7.20	7.70	7.60
Total Carbon %	25.54	19.87	18.49	16.20	22.24	14.02	20.59	18.53
C/N Ratio	9:1	9:1					7.2:1	8.2:1
Chloride %	0.19	0.28	0.94	0.95	0.89	0.45	0.54	0.48

Table 7: Tissue Analysis Harvested Algal Turf Biomass for Floways SF1 and SF2 December 2010-January 2011

Parameter	Dec/Jan 2010/11	
(dry weight basis)	SF1	SF2
N%	2.58	3.19
Ammonium N %	0.11	0.18
Nitrate N %	Nd	Nd
Organic N %	2.47	3.01
P_2O_5 %	1.86	1.81
P %	0.81	0.79
K_2O %	0.86	0.77
S %	0.38	0.35
Ca %	0.92	0.90
Mg %	0.27	0.26
Na %	0.04	0.05
Cu ppm	nd	Nd
Fe ppm	11,588	12,479
Mn ppm	10,188	10,207
Zn ppm	110	109
pH	6.00	6.00
Total Carbon %	15.14	17.73
C/N Ratio	5.9:1	5.6:1
Chloride %	0.05	0.07

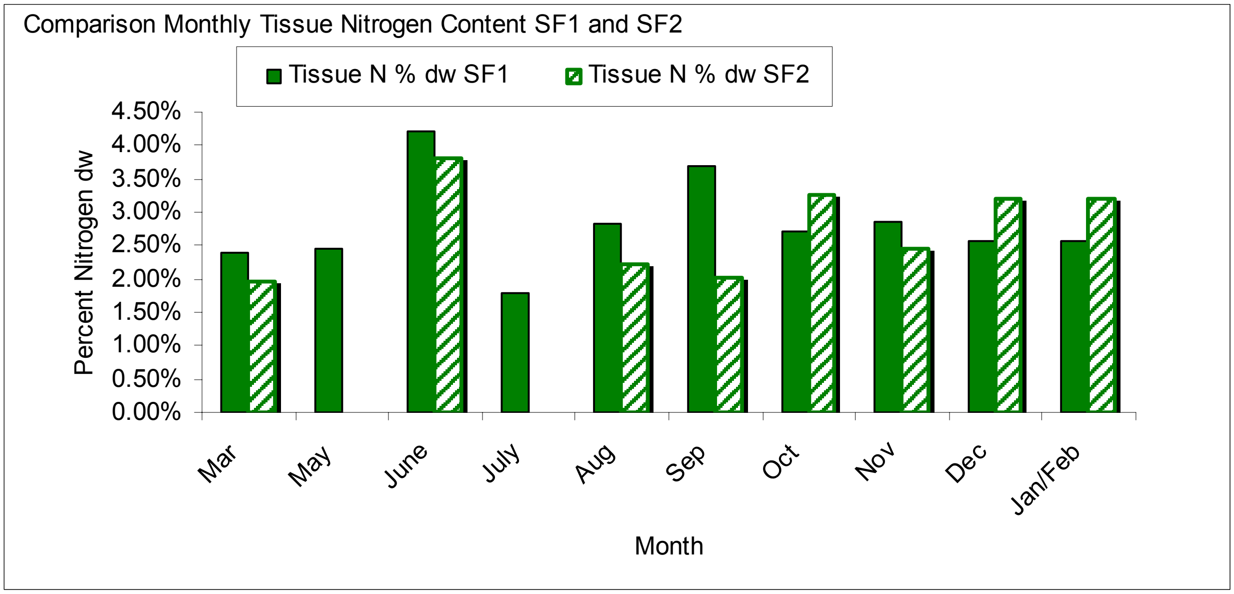


Figure 12. Algal Turf Tissue Nitrogen Content for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

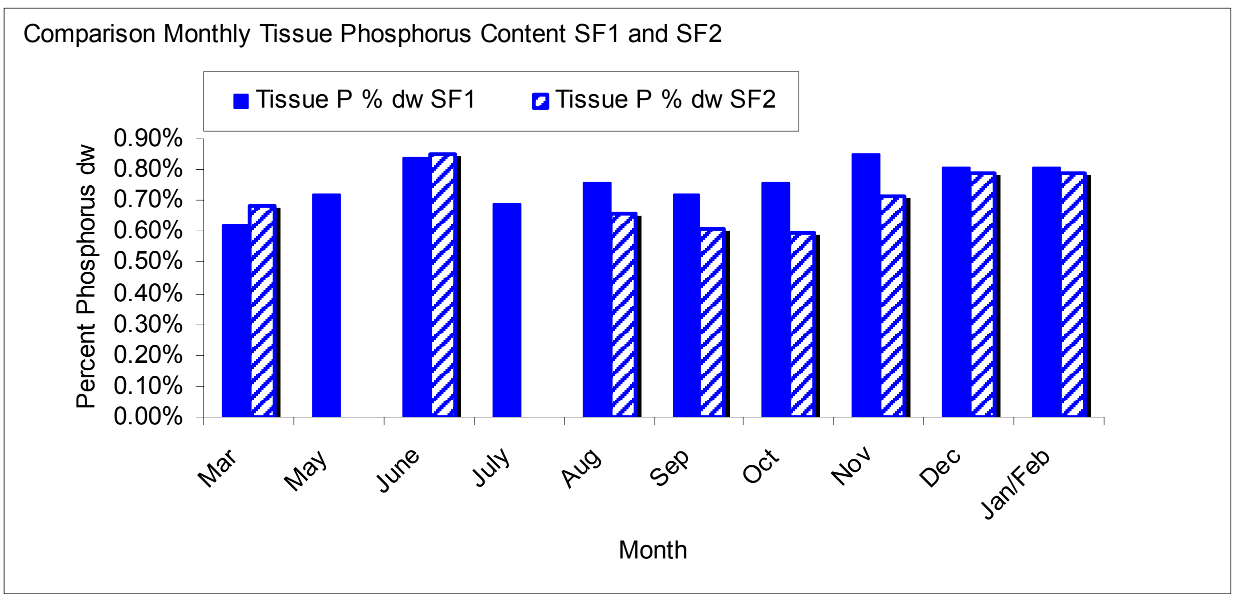
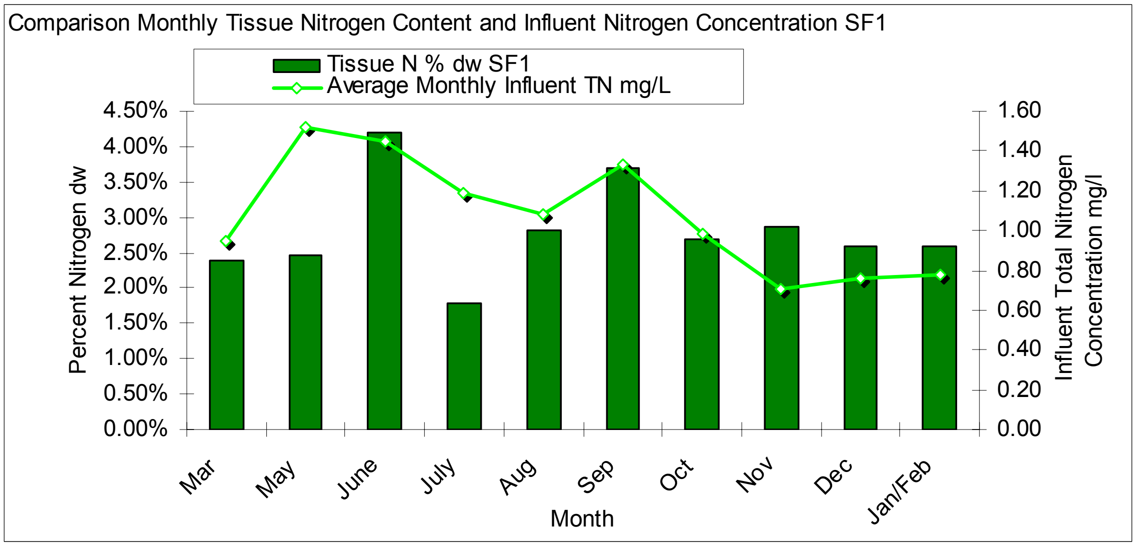


Figure 13. Algal Turf Tissue Phosphorus Content for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program



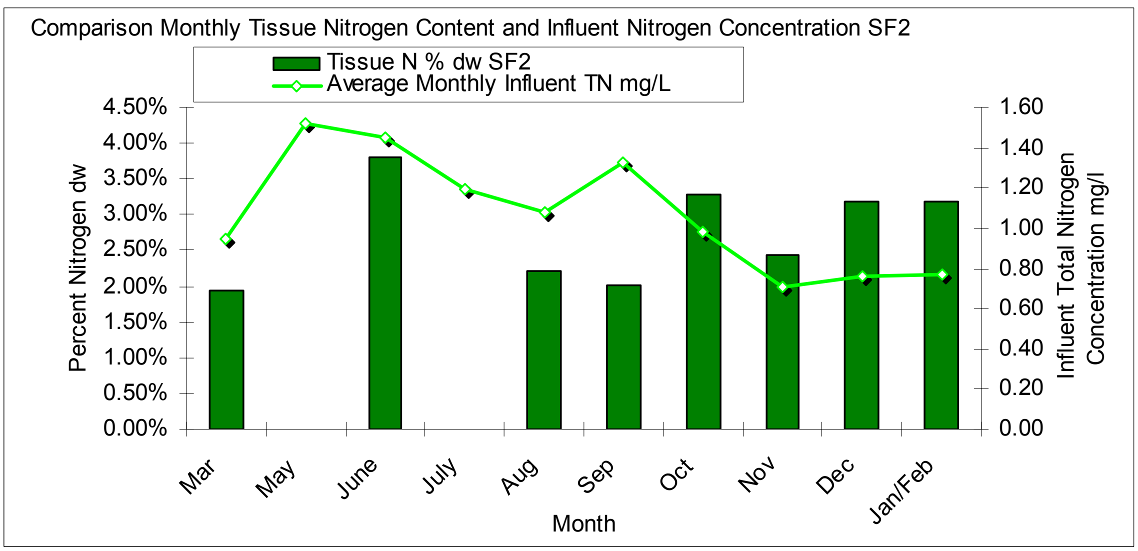
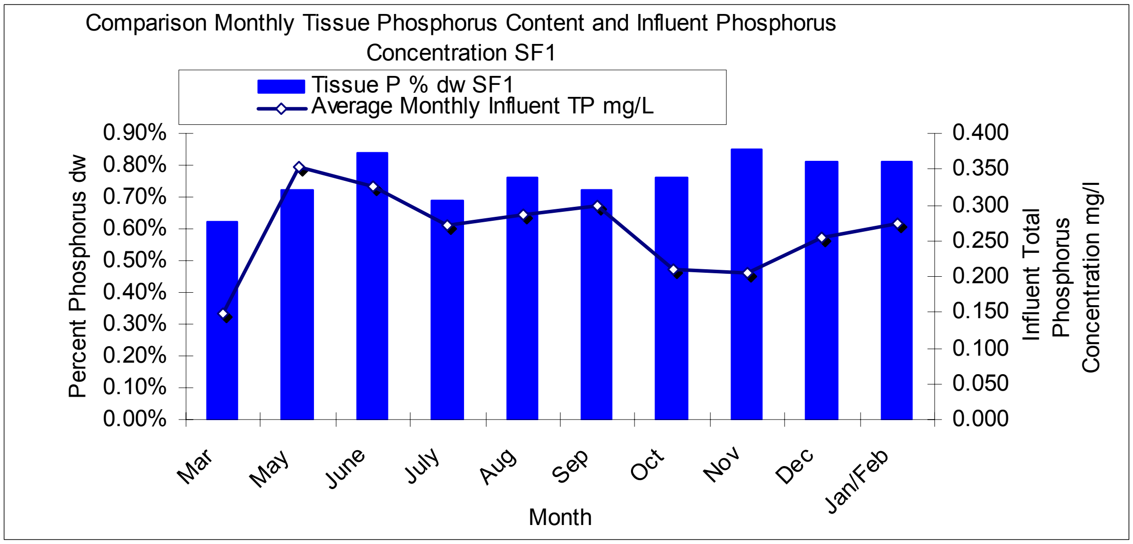


Figure 14. Algal Turf Tissue Nitrogen Content and Influent Total Nitrogen Concentration for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program



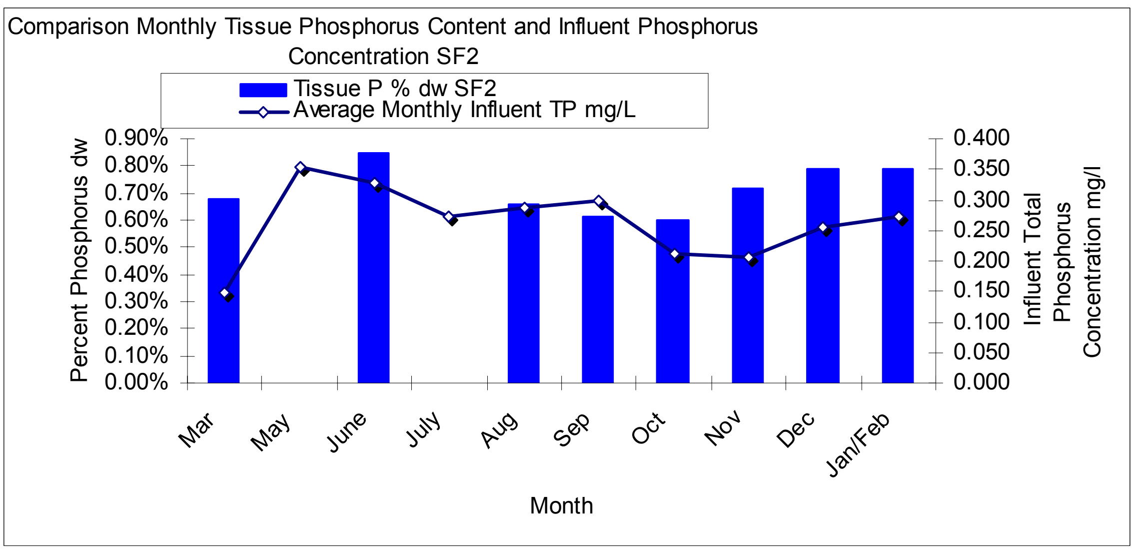


Figure 15. Algal Turf Tissue Phosphorus Content and Influent Total Phosphorus Concentration for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

SECTION 3. SYSTEM ANALYSIS

Nitrogen Dynamics

Total Nitrogen

Presented in Table 8 is a summary of total nitrogen (TN) removal and concentrations through the project term. There was a noticeably higher percent reduction in total nitrogen based upon water quality within SF1 when compared to SF2, and a notably higher reduction during both Q2 and Q3 within both floways as compared to Q1, which may indicate system maturation through establishment of colonies of enzyme producing organisms which facilitate access to a portion of the organic nitrogen. The drop in nitrogen reduction during Q4 is likely attributable to lower temperatures and lower influent levels of available nitrogen. There is no clear indication why SF2 showed lower removal rates, although surging was withheld from SF2 during Q2, which may have contributed to this differential, although the evidence is certainly not conclusive. The TN concentrations for influent and effluent for both floways are shown in Figure 16.

Total Kjeldahl Nitrogen

Presented in Table 9 is a summary of total Kjeldahl nitrogen (TKN) removal and concentrations through the project term. TKN is calculated as the sum of ammonia nitrogen and organic nitrogen. While ammonia nitrogen, which would be biologically available as a nitrogen source, was not analyzed on a regular basis by HydroMentia, the University of Florida did review ammonia nitrogen on several occasions. They found it was present only in low concentrations, and that organic nitrogen was the predominant component of TKN. Therefore, the majority of the total nitrogen was presented to the floway systems as organic nitrogen, most of which appears to have been unavailable for direct plant uptake. This means the turf community had to rely primarily upon the modest levels of nitrate + nitrite nitrogen and ammonia nitrogen. As discussed later in the text, this established a scenario in which these available forms of nitrogen contributed to limiting turf productivity. While TKN was by far the most abundant nitrogen form, composing 93-94% of the total nitrogen, only 68% of the nitrogen removed by SF1, and 46% of the nitrogen removed by SF2 was as TKN, and much of this was likely the available ammonia nitrogen. This suggests that the organic nitrogen within the Santa Fe River at this stretch of the river is recalcitrant, and not significantly vulnerable to enzymatic hydrolysis.

It is not clear why SF1 provided somewhat better TN and TKN removal than SF2. Apparently the turf community associated with SF1 had developed a slightly more effective capability of accessing organic nitrogen. While certainly not conclusive, the one variation between the two floways was the cessation of surging on SF2 for four weeks during Q2, which may have impacted the complexion and capabilities of the turf communities. The TKN concentrations for influent and effluent for both floways are shown in Figure 17.

Nitrate + Nitrite Nitrogen

Presented in Table 10 is a summary of nitrate + nitrite nitrogen (NOx-N) removal and concentrations through the project term. NOx-N is biologically available as a nitrogen source, and appeared to serve as the primary nitrogen source for the algal turf community. Consequently, even though concentrations were comparatively low (0.12 mg/L), percent removal of NO_x-N was high throughout the project term at 55.2% for SF1 and 55.8% for SF2. Of all of the nitrogen removed through the system, 32% was as NOx-N for SF1 and 54% for SF2. The influent and effluent NOx-N concentrations for the monitoring period and both floways are shown in Figure 18.

Table 8: Total Nitrogen Reduction Summary for Floways SF1 and SF2 Q1 through Q4

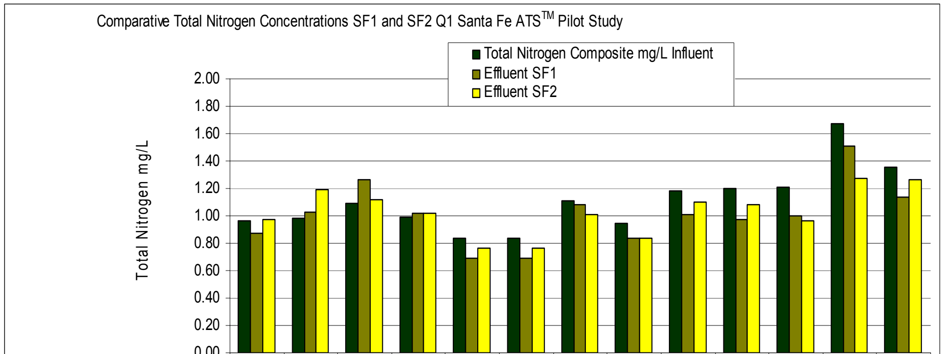
Quarter	Floway	Average Influent TN mg/l	Maximum Influent TN mg/L	Minimum Influent TN mg/L	Standard Deviation mg/L	Average Effluent TN mg/L	Maximum Effluent TN mg/L	Minimum Effluent TN mg/L	Standard Deviation mg/L	Water Quality Based Percent Removal	Harvest Based Percent Removal
Q1	SF1	1.09	1.67	0.83	0.24	1.01	1.51	0.69	0.22	8.31	3.37
	SF2					1.03	1.27	0.77	0.17	3.89	6.05
Q2	SF1	1.31	1.86	0.90	0.28	0.93	1.27	0.34	0.26	29.60	5.34
	SF2					1.04	1.25	0.82	0.12	20.75	3.83
Q3	SF1	1.05	1.41	0.64	0.29	0.85	1.35	0.52	0.27	19.33	7.53
	SF2					0.92	1.40	0.56	0.25	12.99	5.59
Q4	SF1	0.75	1.07	0.53	0.18	0.68	1.10	0.48	0.18	10.19	1.40
	SF2					0.73	1.20	0.54	0.19	6.22	2.53
Total Project Term	SF1	1.07	1.86	0.53	0.31	0.88	1.51	0.34	0.25	18.75	4.64
	SF2					0.94	1.40	0.54	0.22	12.34	4.62

Table 9: Total Kjeldahl Nitrogen (TKN) Reduction Summary for Floways SF1 and SF2 Q1 through Q4

Quarter	Floway	Average Influent TKN mg/l	% of TN	Maximum Influent TKN mg/L	Minimum Influent TKN mg/L	Standard Deviation mg/L	Average Effluent TKN mg/L	% of TN	Maximum Effluent TKN mg/L	Minimum Effluent TKN mg/L	Standard Deviation mg/L	Water Quality Based Percent Removal
Q1	SF1	0.99	90.8	1.60	0.75	0.22	0.97	96.0	1.49	0.67	0.22	2.14
	SF2						0.98	95.1	1.24	0.75	0.16	-2.56
Q2	SF1	1.14	87.0	1.69	0.71	0.30	0.86	92.5	1.17	0.25	0.26	25.85
	SF2						0.97	93.3	1.17	0.77	0.11	15.29
Q3	SF1	0.92	85.7	1.33	0.61	0.27	0.79	92.9	1.28	0.51	0.23	14.02
	SF2						0.86	93.5	1.37	0.56	0.23	6.66
Q4	SF1	0.70	93.3	1.04	0.48	0.20	0.64	94.1	1.02	0.47	0.17	7.52
	SF2						0.70	95.9	1.12	0.50	0.18	3.37
Total Project Term	SF1	0.95	88.8	1.69	0.48	0.28	0.82	93.2	1.49	0.25	0.24	13.90
	SF2						0.89	94.7	1.37	0.50	0.20	6.65

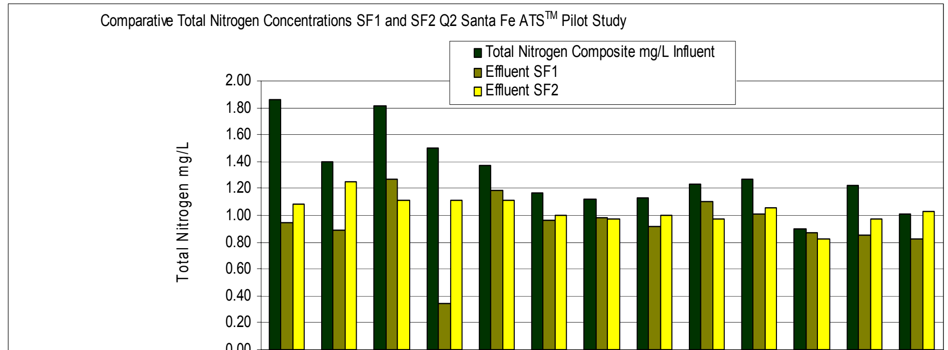
Table 10: Nitrate + Nitrite Nitrogen (NOx-N) Reduction Summary for Floways SF1 and SF2 Q1 through Q4

Quarter	Floway	Average Influent NOx-N mg/l	% of TN	Maximum Influent NOx-N mg/L	Minimum Influent NOx-N mg/L	Standard Deviation mg/L	Average Effluent NOx-N mg/L	% of TN	Maximum Effluent NOx-N mg/L	Minimum Effluent NOx-N mg/L	Standard Deviation mg/L	Water Quality Based Percent Removal
Q1	SF1	0.11	10.1	0.23	0.02	0.06	0.04	4.0	0.11	0.01	0.03	61.9
	SF2						0.05	4.9	0.11	0.01	0.04	59.2
Q2	SF1	0.17	13.0	0.24	0.09	0.05	0.07	7.5	0.27	0.00	0.05	55.0
	SF2						0.07	6.7	0.13	0.01	0.04	57.6
Q3	SF1	0.13	12.4	0.23	0.03	0.08	0.06	7.1	0.14	0.00	0.05	55.9
	SF2						0.06	6.5	0.15	0.00	0.05	56.5
Q4	SF1	0.06	8.0	0.18	0.01	0.05	0.04	5.9	0.14	0.00	0.04	38.7
	SF2						0.04	5.5	0.13	0.00	0.04	38.5
Total Project Term	SF1	0.12	11.2	0.24	0.01	0.07	0.05	5.7	0.27	0.00	0.05	55.2
	SF2						0.05	5.3	0.15	0.00	0.04	55.8



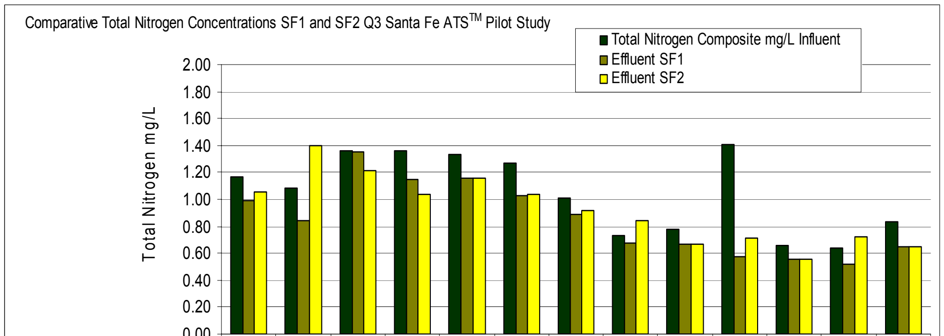
	2/23/10	3/2/10	3/9/10	3/16/10	3/23/10	3/30/10	4/6/10	4/13/10	4/20/10	4/27/10	5/4/10	5/11/10	5/18/10
Total Nitrogen Composite mg/L Influent	0.96	0.98	1.09	0.99	0.83	0.83	1.11	0.95	1.18	1.20	1.21	1.67	1.35
Effluent SF1	0.87	1.03	1.26	1.02	0.69	0.69	1.08	0.84	1.01	0.97	1.00	1.51	1.14
Effluent SF2	0.98	1.19	1.12	1.02	0.77	0.77	1.01	0.84	1.10	1.08	0.96	1.27	1.26

Week Ending



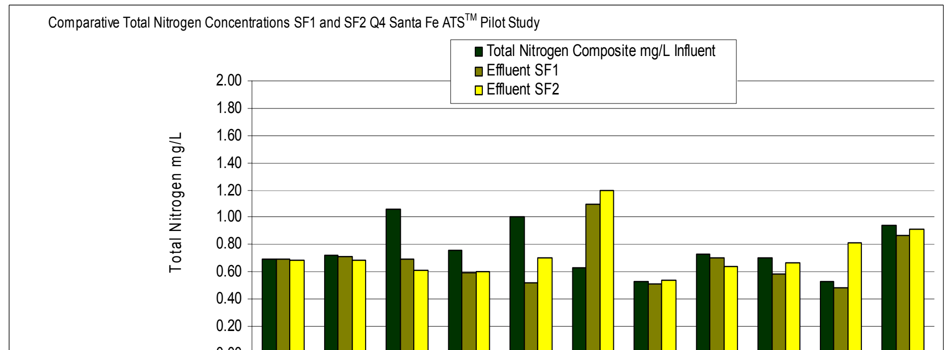
	5/25/10	6/1/10	6/8/10	6/15/10	6/22/10	6/29/10	7/6/10	7/13/10	7/20/10	7/27/10	8/3/10	8/10/10	8/17/10
Total Nitrogen Composite mg/L Influent	1.86	1.40	1.81	1.50	1.37	1.17	1.12	1.13	1.23	1.27	0.90	1.22	1.01
Effluent SF1	0.94	0.89	1.27	0.34	1.18	0.96	0.98	0.92	1.10	1.01	0.87	0.86	0.82
Effluent SF2	1.08	1.25	1.11	1.11	1.12	1.00	0.97	1.00	0.97	1.06	0.82	0.98	1.03

Week Ending



	8/24/10	8/31/10	9/7/10	9/14/10	9/21/10	9/28/10	10/5/10	10/12/10	10/19/10	10/26/10	11/2/10	11/9/10	11/16/10
Total Nitrogen Composite mg/L Influent	1.17	1.08	1.36	1.36	1.33	1.27	1.01	0.73	0.78	1.41	0.65	0.64	0.83
Effluent SF1	0.99	0.85	1.35	1.15	1.16	1.03	0.89	0.68	0.67	0.58	0.56	0.52	0.65
Effluent SF2	1.06	1.40	1.21	1.04	1.16	1.04	0.92	0.84	0.67	0.72	0.56	0.72	0.65

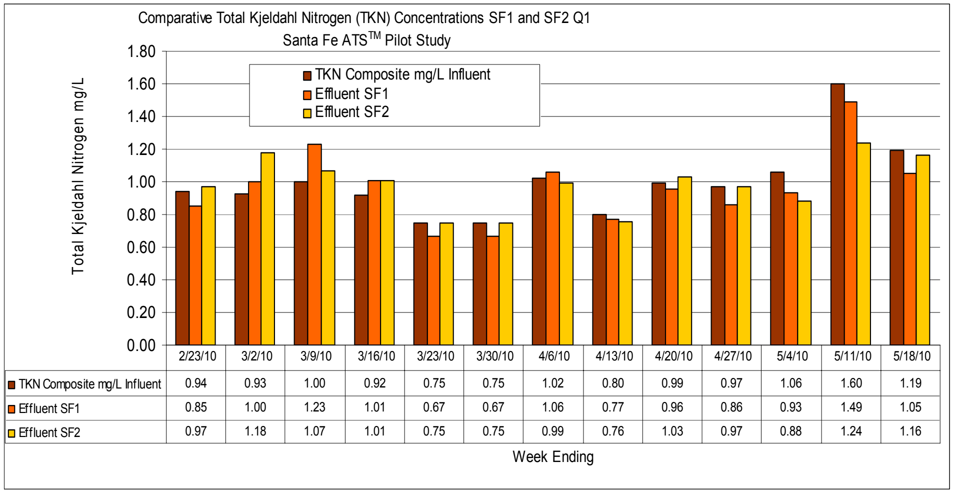
Week Ending



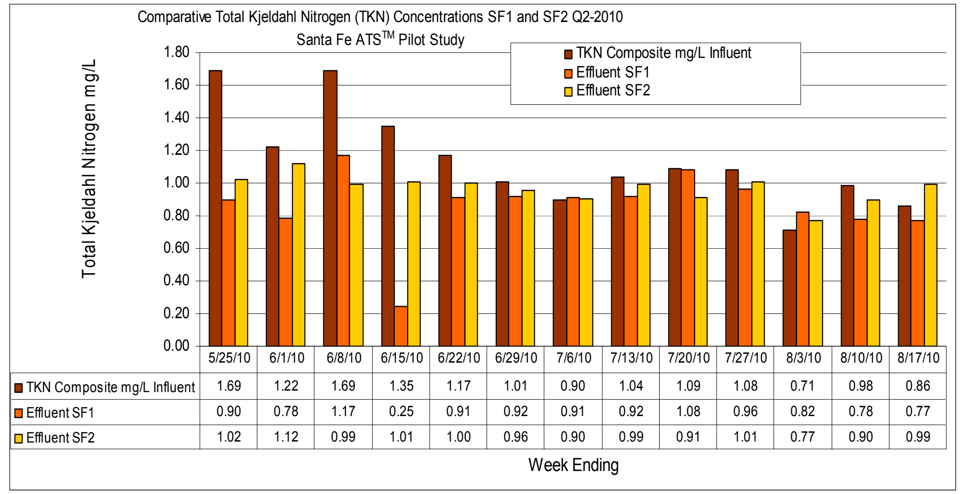
	11/23/10	11/30/10	12/7/10	12/14/10	12/21/10	1/18/11	1/25/11	2/1/11	2/8/11	2/15/11	2/22/11
Total Nitrogen Composite mg/L Influent	0.69	0.72	1.06	0.76	1.01	0.63	0.53	0.73	0.70	0.53	0.94
Effluent SF1	0.70	0.71	0.69	0.59	0.52	1.10	0.51	0.70	0.58	0.48	0.87
Effluent SF2	0.69	0.68	0.61	0.60	0.70	1.20	0.54	0.64	0.67	0.81	0.91

Week Ending

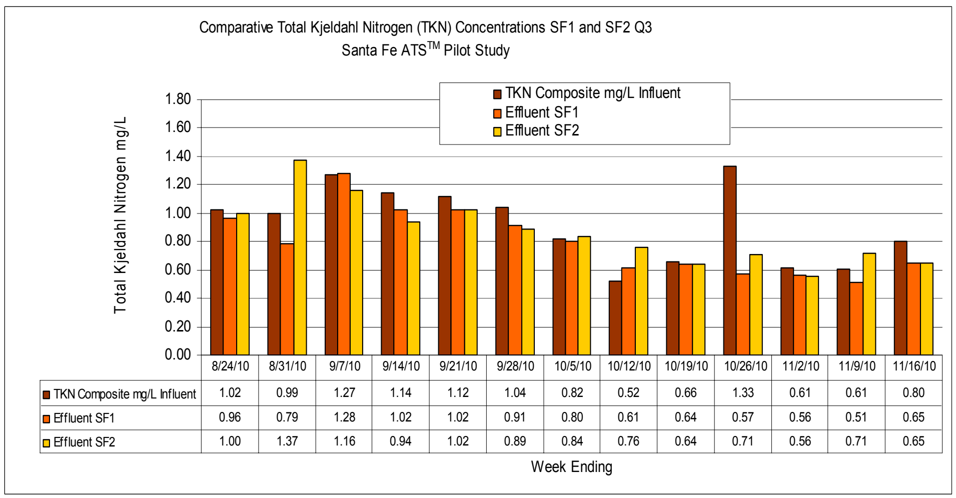
Figure 16: Total Nitrogen Influent and Effluent Concentrations for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program



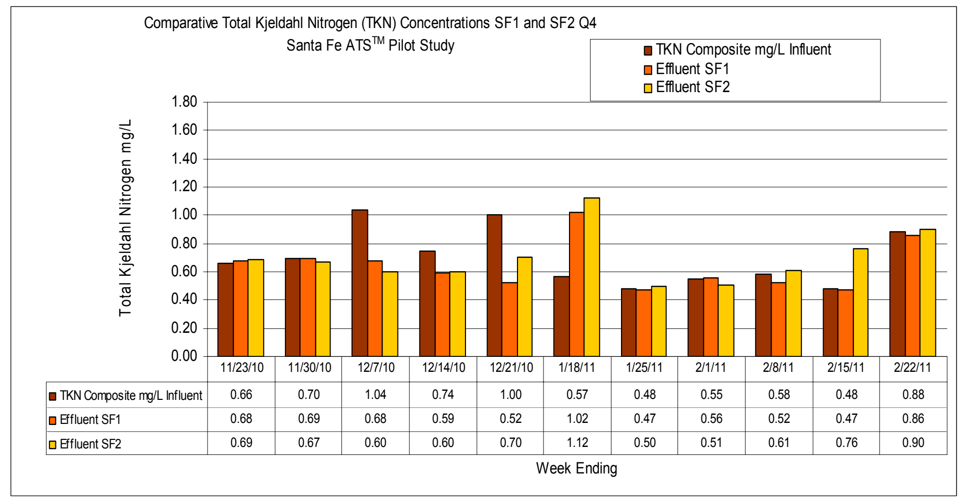
	2/23/10	3/2/10	3/9/10	3/16/10	3/23/10	3/30/10	4/6/10	4/13/10	4/20/10	4/27/10	5/4/10	5/11/10	5/18/10
TKN Composite mg/L Influent	0.94	0.93	1.00	0.92	0.75	0.75	1.02	0.80	0.99	0.97	1.06	1.60	1.19
Effluent SF1	0.85	1.00	1.23	1.01	0.67	0.67	1.06	0.77	0.96	0.86	0.93	1.49	1.05
Effluent SF2	0.97	1.18	1.07	1.01	0.75	0.75	0.99	0.76	1.03	0.97	0.88	1.24	1.16



	5/25/10	6/1/10	6/8/10	6/15/10	6/22/10	6/29/10	7/6/10	7/13/10	7/20/10	7/27/10	8/3/10	8/10/10	8/17/10
TKN Composite mg/L Influent	1.69	1.22	1.69	1.35	1.17	1.01	0.90	1.04	1.09	1.08	0.71	0.98	0.86
Effluent SF1	0.90	0.78	1.17	0.25	0.91	0.92	0.91	0.92	1.08	0.96	0.82	0.78	0.77
Effluent SF2	1.02	1.12	0.99	1.01	1.00	0.96	0.90	0.99	0.91	1.01	0.77	0.90	0.99

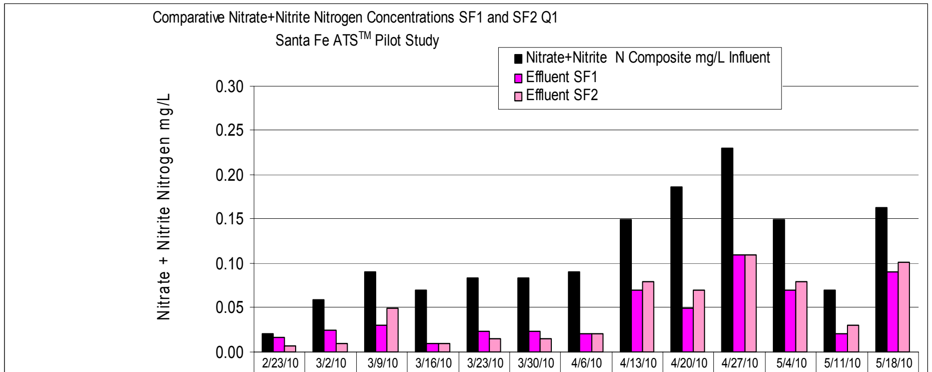


	8/24/10	8/31/10	9/7/10	9/14/10	9/21/10	9/28/10	10/5/10	10/12/10	10/19/10	10/26/10	11/2/10	11/9/10	11/16/10
TKN Composite mg/L Influent	1.02	0.99	1.27	1.14	1.12	1.04	0.82	0.52	0.66	1.33	0.61	0.61	0.80
Effluent SF1	0.96	0.79	1.28	1.02	1.02	0.91	0.80	0.61	0.64	0.57	0.56	0.51	0.65
Effluent SF2	1.00	1.37	1.16	0.94	1.02	0.89	0.84	0.76	0.64	0.71	0.56	0.71	0.65



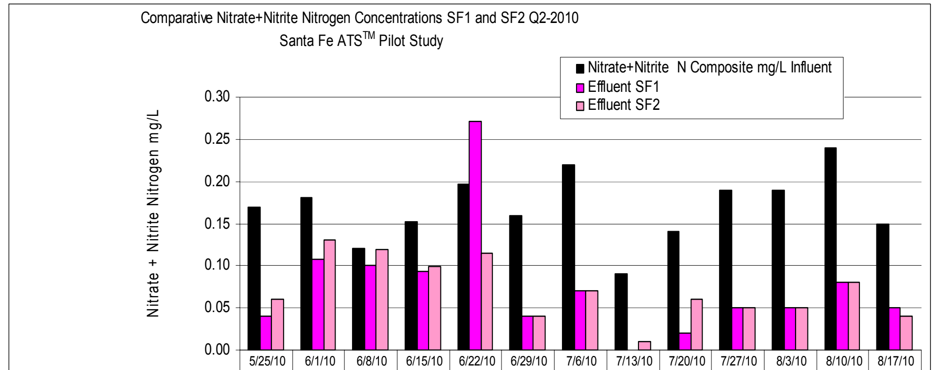
	11/23/10	11/30/10	12/7/10	12/14/10	12/21/10	1/18/11	1/25/11	2/1/11	2/8/11	2/15/11	2/22/11
TKN Composite mg/L Influent	0.66	0.70	1.04	0.74	1.00	0.57	0.48	0.55	0.58	0.48	0.88
Effluent SF1	0.68	0.69	0.68	0.59	0.52	1.02	0.47	0.56	0.52	0.47	0.86
Effluent SF2	0.69	0.67	0.60	0.60	0.70	1.12	0.50	0.51	0.61	0.76	0.90

Figure 17: TKN Influent and Effluent Concentrations for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program



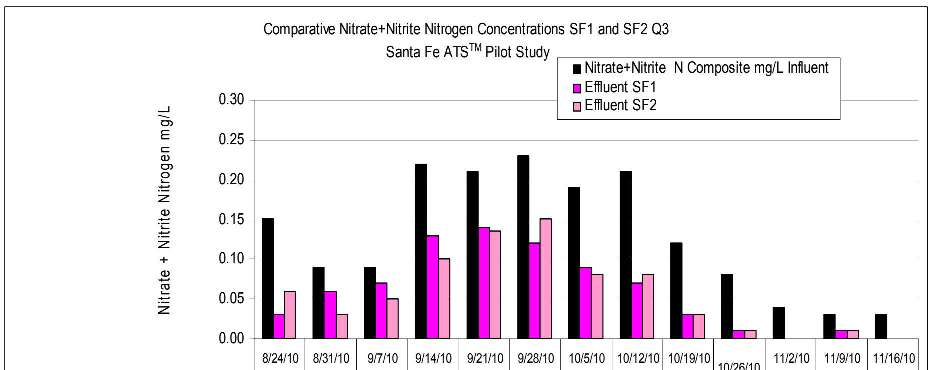
	2/23/10	3/2/10	3/9/10	3/16/10	3/23/10	3/30/10	4/6/10	4/13/10	4/20/10	4/27/10	5/4/10	5/11/10	5/18/10
Nitrate+Nitrite N Composite mg/L Influent	0.02	0.06	0.09	0.07	0.08	0.08	0.09	0.15	0.19	0.23	0.15	0.07	0.16
Effluent SF1	0.02	0.03	0.03	0.01	0.02	0.02	0.02	0.07	0.05	0.11	0.07	0.02	0.09
Effluent SF2	0.01	0.01	0.05	0.01	0.02	0.02	0.02	0.08	0.07	0.11	0.08	0.03	0.10

Week Ending



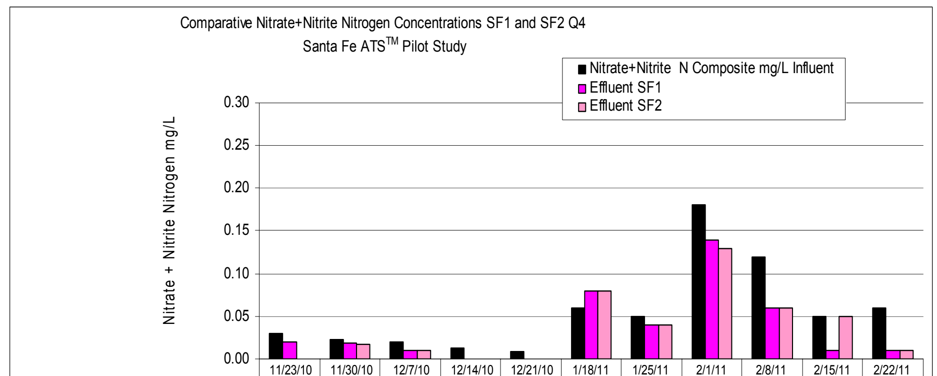
	5/25/10	6/1/10	6/8/10	6/15/10	6/22/10	6/29/10	7/6/10	7/13/10	7/20/10	7/27/10	8/3/10	8/10/10	8/17/10
Nitrate+Nitrite N Composite mg/L Influent	0.17	0.18	0.12	0.15	0.20	0.16	0.22	0.09	0.14	0.19	0.19	0.24	0.15
Effluent SF1	0.04	0.11	0.10	0.09	0.27	0.04	0.07	0.00	0.02	0.05	0.05	0.08	0.05
Effluent SF2	0.06	0.13	0.12	0.10	0.12	0.04	0.07	0.01	0.06	0.05	0.05	0.08	0.04

Week Ending



	8/24/10	8/31/10	9/7/10	9/14/10	9/21/10	9/28/10	10/5/10	10/12/10	10/19/10	10/26/10	11/2/10	11/9/10	11/16/10
Nitrate+Nitrite N Composite mg/L Influent	0.15	0.09	0.09	0.22	0.21	0.23	0.19	0.21	0.12	0.08	0.04	0.03	0.03
Effluent SF1	0.03	0.06	0.07	0.13	0.14	0.12	0.09	0.07	0.03	0.01	0.00	0.01	0.00
Effluent SF2	0.06	0.03	0.05	0.10	0.14	0.15	0.08	0.08	0.03	0.01	0.00	0.01	0.00

Week Ending



	11/23/10	11/30/10	12/7/10	12/14/10	12/21/10	1/18/11	1/25/11	2/1/11	2/8/11	2/15/11	2/22/11
Nitrate+Nitrite N Composite mg/L Influent	0.03	0.02	0.02	0.01	0.01	0.06	0.05	0.18	0.12	0.05	0.06
Effluent SF1	0.02	0.02	0.01	0.00	0.00	0.08	0.04	0.14	0.06	0.01	0.01
Effluent SF2	0.00	0.02	0.01	0.00	0.00	0.08	0.04	0.13	0.06	0.05	0.01

Week Ending

Figure 18: Nitrate + Nitrite -N Influent and Effluent Concentrations for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

Nitrogen Mass Removal and Areal Removal Rates

Mass removal and areal removal rates for nitrogen can be calculated from both water quality data and from harvest data, with the water quality data considered the more reliable because of the homogeneity of the matrix (water), and the higher level of reliability of composite sampling and analytical procedures. Nonetheless comparing the two calculations provides insight into system dynamics.

Accountability of nitrogen within an ATS™ system is complicated by the fact that not only can dissolved and particulate nitrogen in the water be transformed into gaseous forms which escape into the atmosphere, but also atmospheric elemental nitrogen (N_2) can in certain situations be "fixed" by certain organisms, including some *Cyanobacteria.* Therefore, comparing harvest based nitrogen removals with water quality based nitrogen removals not only serves to check procedural reliability, but also provides an indication of atmospheric nitrogen transfers. Nitrogen may be removed from the system and lost to the atmosphere through ammonia volatilization or denitrification. Nitrogen can be accessed from the atmosphere through nitrogen fixation.

Ammonia volatilization rates are typically significant only at high pH levels (>10). While the ATS™ effluent under low alkalinity conditions can approach 10 during the daytime, typically ammonia levels in native surface waters are so low, that the extent of loss through ammonia volatilization is low. Ammonia losses through volatilization would be a more likely consideration with domestic and some industrial and agricultural wastewaters, which can have much higher ammonia levels. It is not likely, but not impossible, that ammonia volatilization is a factor in the nitrogen dynamics of the Santa Fe ATS™ Pilot.

In micro-aerobic or anaerobic environments in which labile organic compounds are present, nitrate nitrogen can be converted by certain bacteria into atmospheric N_2 -- a process known as denitrification. Typically, the flows on the ATS™ are highly oxygenated, and the nitrate levels are low, so denitrification is not expected to be a factor in nitrogen dynamics. As with ammonia volatilization, for wastewaters the possibility of conditions are better suited for denitrification.

The oxidation of reduced nitrogen (ammonia) to nitrate occurs through a two stage chemoautotrophic process known as nitrification. This reaction occurs under highly oxygenated conditions, and when there is an opportunity for the chemoautotrophic bacteria to establish a working biomass. Nitrification can occur on fixed film systems, and certainly could be promoted on an ATS™ floway. The frequency of harvesting however would be expected to inhibit development of a stable base of nitrifying bacteria, and the relevance of nitrification within the framework of an ATS™ has yet to be established.

Nitrogen fixation occurs when specialized organisms (e.g. certain *Cyanobacteria*) convert atmospheric nitrogen to ammonia nitrogen. Nitrogen fixation by *Cyanobacteria* is typically activated when there is a relative paucity of available nitrogen within the water. It is not unusual for the nitrogen within native waters in Florida to be largely composed of organically bound nitrogen. The biological availability of nitrogen bound to organic complexes depends upon the relative vulnerability of these complexes to surrender its amine groups through enzymatic hydrolysis (e.g. deaminase). If the organic nitrogen is recalcitrant, now commonly referred to as refractory dissolved organic nitrogen or RDON, and there is little available ammonia or nitrate nitrogen within the water, then the probability of nitrogen fixation will typically increase.

Mass nitrogen removal (also applicable to other nutrients) based upon harvested biomass is calculated as:

$N_{mh} = (sH_w)n$

Where N_{mh} = mass of nitrogen removed through harvesting
s = solids content as fraction of wet harvest
H_w = mass of wet harvest
(sH_w) = mass of dry harvest
n = tissue nitrogen content as fraction of dry harvest

Mass removal based upon water quality is calculated as

$N_{mw} = I_n Q_I – E_n Q_E$

Where P_{mw} = mass of nitrogen removed based upon water quality
I_p = Influent total nitrogen concentration
E_p = Effluent total nitrogen concentration
Q_I = Influent totalized flow
Q_E = Effluent totalized flow

Some insight into the nature of the nitrogen dynamics within an ATS™ system can be gained by comparing the harvest based and water quality based nitrogen removals, and through review of changes in organic, ammonia, and nitrate + nitrite nitrogen from influent to effluent. The following guidelines are helpful in making an assessment of nitrogen movement through the floway.

- If total nitrogen removed through harvest based calculations >> total nitrogen removed through water quality based calculation, then nitrogen fixation may be involved.
- If total nitrogen removed through harvest based calculations << total nitrogen removed through water quality based calculations, then denitrification or ammonia volatilization (and possibly ecological emigration through hatching insect pupae or external predation) may be involved.
- If total nitrogen removed through harvest based calculation ≈ total nitrogen removed through water quality based calculations, then direct plant uptake is likely the dominant removal mechanism.
- If the total nitrogen removed based upon water quality based calculations is dominated by Total Kjeldahl Nitrogen (TKN--which is the sum of organic and ammonia nitrogen) removal and there is negligible nitrate removal, then direct ammonia uptake, possibly aided by substantial deaminase activity, is likely the dominant removal mechanisms.
- If there is a net removal of TKN based upon water quality based calculations and there is an increase in nitrate concentration within the effluent, then active nitrification is indicated.
- If there is minimal removal of TKN when compared to nitrate removal, based upon water quality based calculation then the organic nitrogen is likely resistant to enzymatic hydrolysis, the ammonia levels are low, and direct nitrate uptake and/or denitrification are likely the dominant removal mechanisms.

Critical to the quantification of biological system performance efficiency over an extended period and a wide range of seasonal conditions is the determination of areal removal rates, expressed as mass removal of the targeted nutrient, per unit process area per unit time. Typically areal removal rate has been expressed by water resource managers as grams of nutrients removed per square meter of process area over a year or g/m^2-yr. The higher the areal removal rate the smaller the required footprint for a common mass removal requirement. A biological system with a higher areal removal rate is likely to be more cost effective than biological systems with lower areal removal rates[6]. High areal removal rates are particularly advantageous when land availability is limited or land costs are very high.

[6] While higher areal removal rates imply improved cost effectiveness, it is only through long term (50+ years) economic assessments (e.g. Present Worth Analysis), and detailed, objective environmental review that such cost effectiveness can be verified.

For Q1, total nitrogen mass removal and areal removal rates (ARR) for the water quality based and harvest based calculations tracked reasonably well. For SF1, the water quality based mass removal (816 g) and ARR (70.47 g/m^2-yr) were higher than the harvest based mass removal (301 g) and ARR (33.79 g/m^2-yr), suggestive that nitrogen fixation was not a factor in nitrogen dynamics, and that while direct uptake (as nitrate-N and ammonia-N), was likely the dominant removal process, other mechanisms may have also been involved. For SF2, the water quality based mass removal (374 g) and ARR (32.33 g/m^2-yr) were somewhat lower than for SF1 and were similar, but lower than the harvest based mass removal (530 g) and ARR (59.44 g/m^2-yr). Direct nitrogen uptake (as nitrate-N and ammonia-N) was the most likely removal mechanism associated with SF2.

For Q2, for both floways, the total nitrogen mass removal and areal removal rates (ARR) based upon water quality calculations increased substantially. However, the harvest based total nitrogen based mass removal and ARR were considerably lower than the water quality based values for Q2 for both floways, and were similar to values noted for Q1. For Q2 with SF1, the water quality based mass removal (3,766 g) and ARR (325.09 g/m^2-yr) were much higher than the harvest based removal (726 g) and ARR (62.63 g/m^2-yr), suggestive as with Q1 that nitrogen fixation was not a factor in nitrogen dynamics, and direct uptake (as nitrate-N and ammonia-N) is likely a major contributing removal process, although because of the extent of the divergence between harvest based and water quality based, other mechanisms, such as emigration, loss during harvest, denitrification and ammonia volatilization may well be involved at a substantial level. For Q2 with SF2, the water quality based removal (2,640 g) and ARR (227.91 g/m^2-yr) increased from Q1, but not to the extent as SF1. For SF2 the harvest based removal (521 g) and ARR (44.94 g/m^2-yr) were similar to those noted for SF2 during Q1, and like SF1, were notably lower than the water quality based values for Q2.

For Q3, for both floways, the total nitrogen mass removal and areal removal rates (ARR) based upon water quality calculations decreased from Q2, but were higher than Q1. The harvest based total nitrogen based mass removal and ARR were lower than the water quality based values for Q2 for both floways, and were similar to values noted for Q1. For Q3 with SF1, the water quality based mass removal (1,888 g) and ARR (163.00 g/m^2-yr) were much higher than the harvest based removal (640 g) and ARR (55.24 g/m^2-yr), suggestive as with Q1 and Q2 that nitrogen fixation was not a factor in nitrogen dynamics, and direct uptake (as nitrate-N and ammonia-N) is likely a major contributing removal process, although because of the extent of the divergence between harvest based and water quality based, other mechanisms, such as emigration, harvest losses, denitrification and ammonia volatilization may well be involved at a substantial level. For Q3 with SF2, the water quality based removal (1,269 g) and ARR (109.55 g/m^2-yr) decreased from Q2. For SF2 the harvest based removal (578 g) and ARR (49.88 g/m^2-yr) were similar to those noted for SF2 during Q2 and Q1, and like SF1, were notably lower than the water quality based values for Q2.

For Q4, for both floways, the total nitrogen mass removal and areal removal rates (ARR) based upon water quality calculations and harvest based calculations were lower than any of the previous quarters. This appears to be attributable to lower water temperatures and lower NOx-N levels. The harvest based total nitrogen based mass removal and ARR were lower than the water quality based values for Q4 for both floways. For Q4 with SF1, the water quality based mass removal (686 g) and ARR (53.30 g/m^2-yr) were much higher than the harvest based removal (136 g) and ARR (19.07g/m^2-yr), suggestive as with previous quarters that nitrogen fixation was not a factor in nitrogen dynamics, and direct uptake (as NOx-N and ammonia-N) is likely a major contributing removal process, although because of the extent of the divergence between harvest based and water quality based, other mechanisms, such as emigration, harvest losses, denitrification and ammonia volatilization may well be involved at a substantial level. For Q4 with SF2, the water quality based removal (332 g) and ARR (33.86 g/m^2-yr) were also much higher than the harvest based removal (135 g) and ARR (18.97 g/m^2-yr).

For the combined monitoring period of Q1 through Q4 the total nitrogen mass removal based upon water quality calculations was 7,019g and 4,616 g for SF1 and SF2 respectively. The total nitrogen mass removal for this same time period based upon harvest calculations was 1,739 g and 1,728 g for SF1 and SF2 respectively. Both floways show the same trends, with a substantial increase in nitrogen removal during Q2, with the removals dropping off somewhat during Q3 and Q4, and with water quality based calculations considerably higher than harvest based calculations. Similar patterns are seen with total nitrogen ARR for the combined Q1 through Q4 monitoring period, with water quality based ARR being 157.57 g/m^2-yr and 103.60 g/m^2-yr for SF1 and SF2, respectively and the harvest based total nitrogen for the same period being 45.97 g/m^2-yr and 44.08 g/m^2-yr for SF1 and SF2, respectively. These trends in total nitrogen removal are shown in Figures 19 and 20.

For Q1 removal patterns for both TKN and NOx-N support the assessment that during this time period, the performances of SF1 and SF2 in terms of nitrogen removal were similar. It is clear, as noted previously, that during Q1 there was a preference for biological uptake of NOx-N, as the NOx-N mass removal (SF1 = 628 g; SF2 = 602 g) well exceeded the TKN mass removal (SF1 = 188 g; SF2 =-228 g) for both floways, even though the average influent TKN concentration (0.99 mg/L) was nine times higher than the average influent NOx-N concentration (0.11 mg/L). These trends are also seen in the comparative ARR values for Q1.

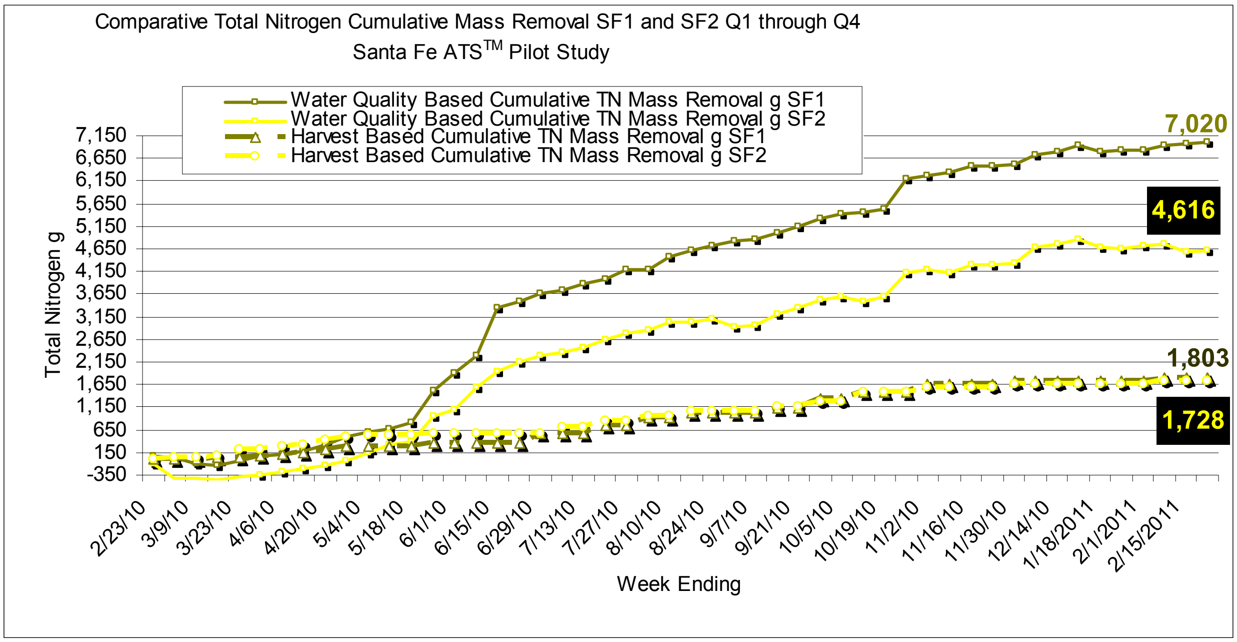


Figure 19: Total Nitrogen Cumulative Mass Removal for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

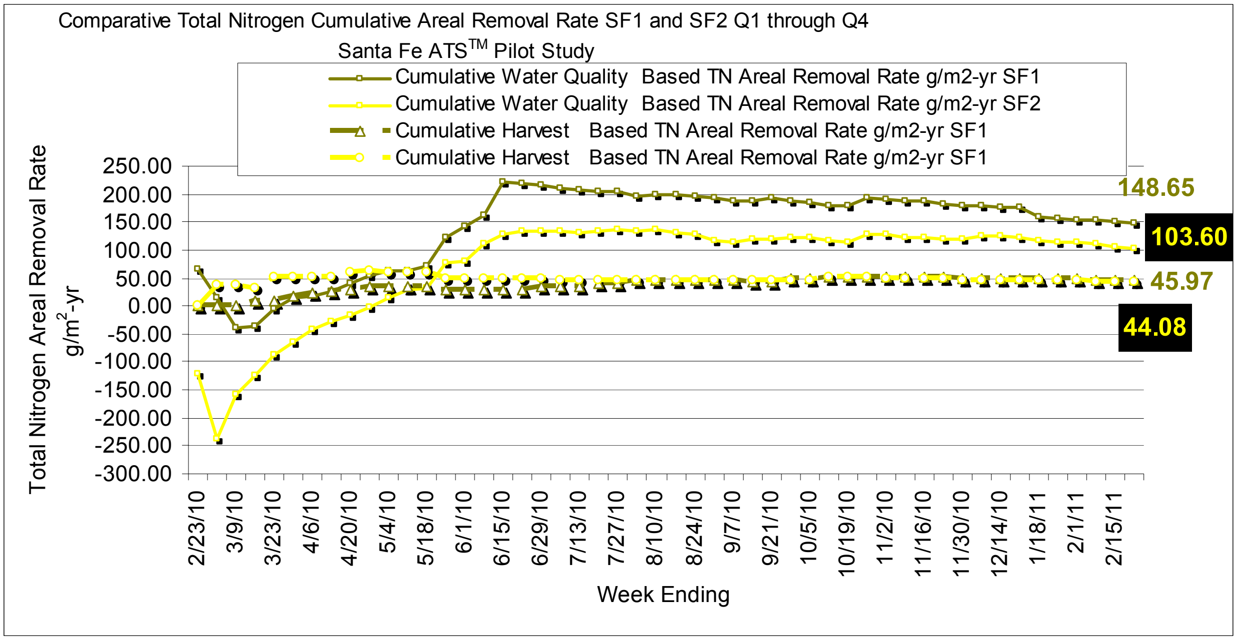


Figure 20: Total Nitrogen Cumulative Areal Removal Rates for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

For Q2 there was a shift in removal patterns for both TKN and NOx-N with the TKN-N mass removal (SF1 = 2,864 g; SF2 = 1,694 g) exceeding the NOx-N mass removal (SF1 = 902 g; SF2 =946 g) for both floways, even though NOx-N mass removal increased from Q1. As would be expected, the TKN ARR increased accordingly for Q2-1010, with values of 247.22 g/m^2-yr and 146.24 g/m^2-yr for SF1 and SF2 respectively, as did the NOx-N ARR for Q2, with values of 77.87 g/m^2-yr and 81.67 g/m^2-yr for SF1 and SF2 respectively. This pattern is indicative of the system being more effective in rendering organic nitrogen more accessible.

For Q3, the TKN-N mass removal (SF1 = 1,196 g; SF2 = 568 g) exceeded the NOx-N mass removal for SF1, but not for SF2 (SF1 = 693 g; SF2 =701 g). Both the TKN and the NOx-N mass removal decreased from Q2, but were higher than Q1. As would be expected, the TKN ARR decreased accordingly for Q3 as compared to Q2, with values of 103.23 g/m^2-yr and 49.04 g/m^2-yr for SF1 and SF2 respectively, as did the NOx-N ARR for Q3, with values of 59.78 g/m^2-yr and 60.51 g/m^2-yr for SF1 and SF2 respectively.

For Q4, the TKN-N mass removal (SF1 = 353 g; SF2 = 166 g) exceeded the NOx-N mass removal for SF1 and equaled the NOx-N removal for SF2 (SF1 = 167 g; SF2 =166 g). Both the TKN and the NOx-N mass removal decreased considerably from the previous quarters. The TKN ARR decreased accordingly for Q4 as compared to the previous quarters, with values of 36.01 g/m^2-yr and 16.89 g/m^2-yr for SF1 and SF2 respectively, as did the NOx-N ARR for Q4, with values of 16.99 g/m^2-yr and 16.97 g/m^2-yr for SF1 and SF2 respectively.

For the combined monitoring period of Q1 through Q4 the TKN mass removal was 4,602 g and 2,200 g for SF1 and SF2 respectively. For the same time period the NOx-N mass removal was 2,418 g and 2,416 g for SF1 and SF2 respectively. For the combined monitoring period of Q1 through Q4 the TKN ARR was 103.29 g/m^2-yr and 49.38 g/m^2-yr for SF1 and SF2 respectively. For the same time period the NOx-N ARR was 54.28 g/m^2-yr and 54.22 g/m^2-yr for SF1 and SF2 respectively. These trends are shown in Figures 21 through 24.

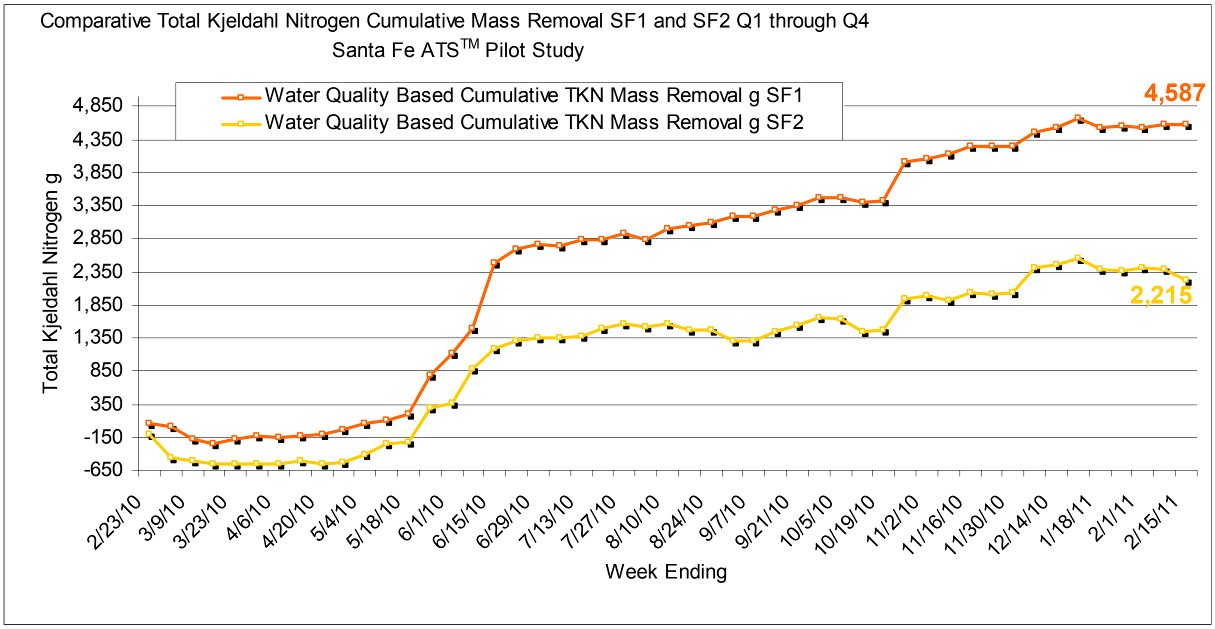


Figure 21: TKN Cumulative Mass Removal for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

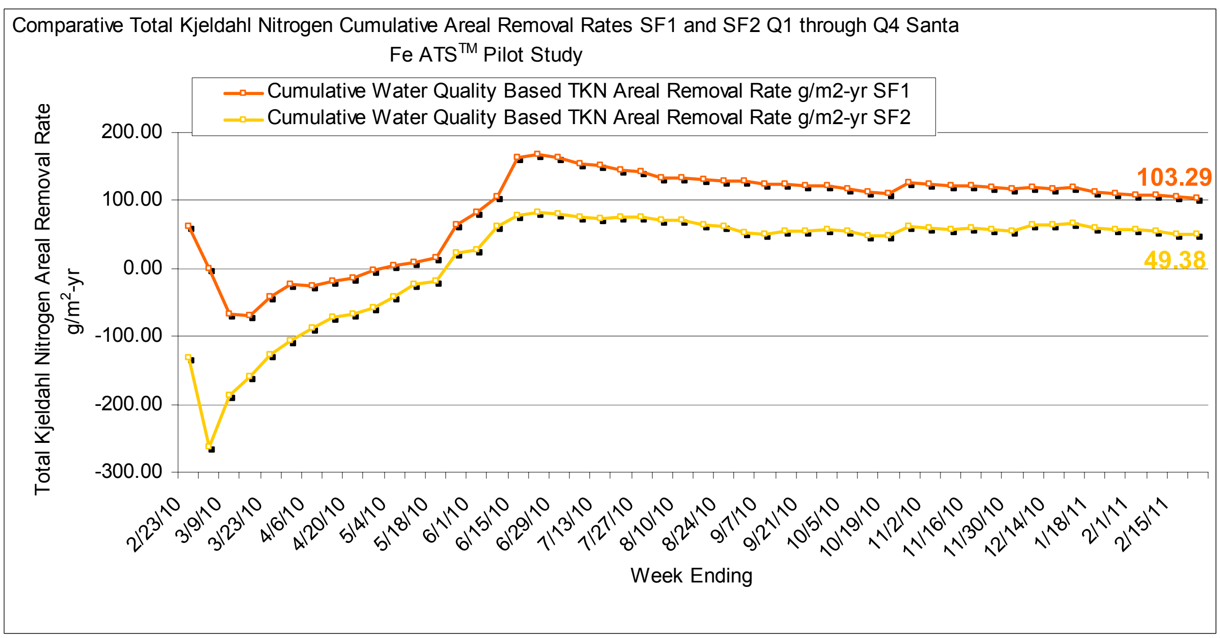


Figure 22: TKN Cumulative Areal Removal Rates for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

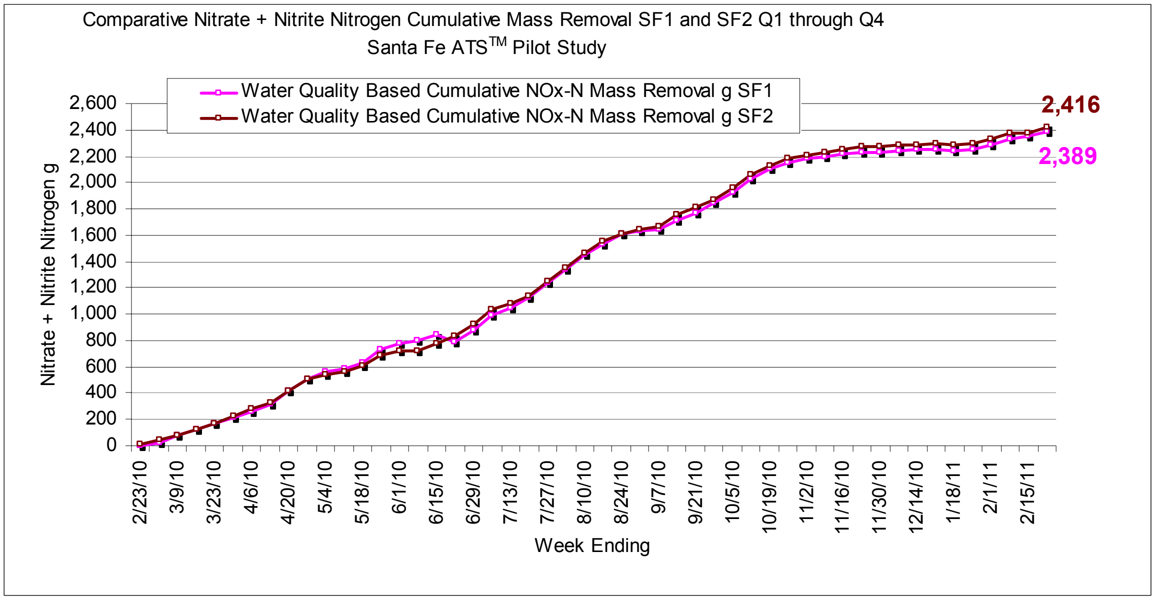


Figure 23: NOx-N Cumulative Mass Removal for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

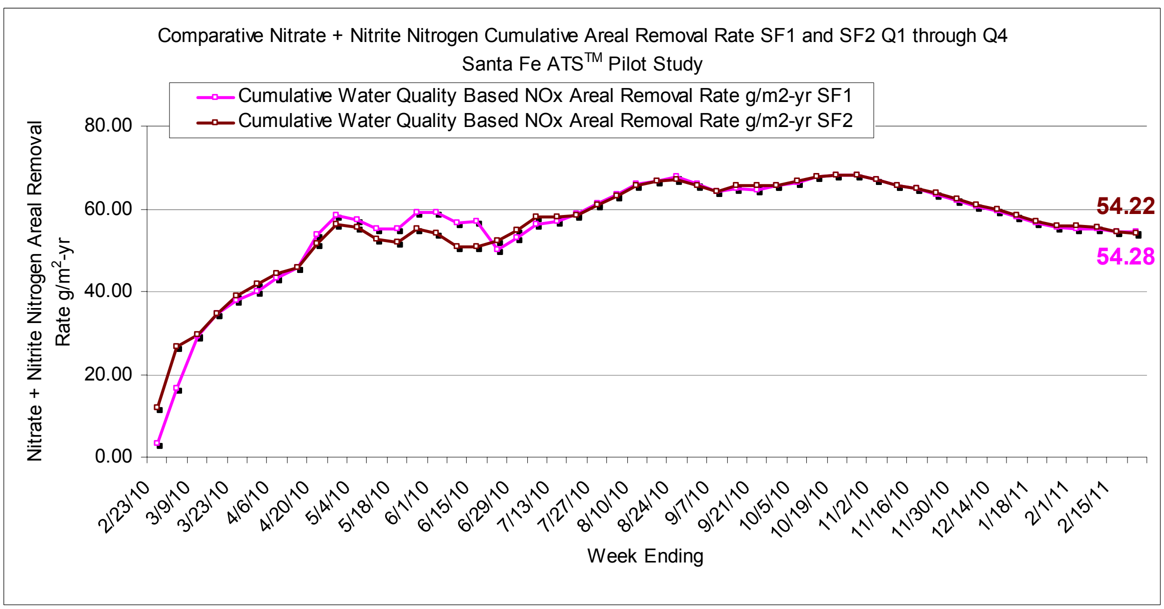


Figure 24: NOx-N Cumulative Areal Removal Rates for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

During Q1, the Santa Fe River influent was comparatively low in nitrogen, demonstrating a TN:TP ratio of only 5.1 (based upon weight), which is below what might be considered the optimal range of approximately 9 to 20. This ratio was somewhat lower during Q2 at 4.5; Q3 at 4.2; and Q4 at 3.0. Generally, the lower the N:P ratio, the greater the selective advantage for *Cyanobacteria* and the more likely nitrogen fixation. However, this should be viewed as a general guideline, recognizing that the relative abundance of nutrients is only one factor involved in establishing the complexion and diversity of an algal turf community.

When the ratio of what would be generally viewed as available nutrients is considered, in this case NOx-N:OP, the Q1 ratio was 0.72: the Q2 ratio was 0.71; the Q3 ratio was 0.60 and the Q4 ratio was 0.29, indicating organisms may find phosphorus more accessible than nitrogen. This would appear ideal for the establishment of nitrogen fixers on the floway. However, as noted, during Q2 through Q4 it appears evident that much of the TKN became available, particularly with SF1, either because the percentage of TKN that was ammonia-N increased; there was an increase in deaminase activity or other environmental factors which rendered the organic fraction available; or both. The availability of TKN would therefore increase the ratio of available nitrogen to available phosphorus. In any case, there was no evidence of nitrogen fixation during the project term[7]. There was indication, as noted earlier, that nitrogen removal may extend beyond direct plant uptake, and could be associated with either large scale ecological emigration; denitrification and/or possibly ammonia volatilization; or a combination of these. Also, the notable difference between harvest based and water quality based mass removal calculations may be attributable to the lower reliability typically associated with harvest based data. The fact that the disparity between harvest based and water quality based mass removal calculations was noted with both total nitrogen and total phosphorus provides some indication that if error is involved, it is probably not attributable to a specific laboratory analytical method (otherwise the error would be seen only with that method and the associated parameter), but more likely to crop management and sampling methods.

It is not clear why there was more effective organic and total nitrogen removal across SF1 when compared to SF2. As noted previously, SF1 did maintain surging through the monitoring period, while SF2 was purposely deprived of surged flow for about four weeks during Q2. As a result of this, some differences in the composition of the turf community was noted, and it is possible that some of the enzyme producing organisms were not as predominant on SF2.

[7] Note that nitrogen fixation would be indicated by a greater nitrogen mass within the harvest when compared to that calculated through water quality data. In fact the opposite was the case for all quarters.

Phosphorus Dynamic

Total Phosphorus

Trends in total phosphorus (TP) concentration for the full project term are summarized in Table 11. The TP concentrations for influent and effluent for both floways are shown in Figure 25. Performance in terms of phosphorus reduction was similar over the project term for the two floways.

Ortho Phosphorus

Trends in total phosphorus (TP) concentration for the full project term are summarized in Table 12. The OP concentrations for influent and effluent for both floways are shown in Figure 26. It is noteworthy that not only does SF2 show lower levels of net OP removal than SF1, but also a slightly higher OP percentage of TP within the effluent, when compared to SF1. The implication is that within SF2, particularly during Q2, considering the fact that phosphorus removals are similar for both floways, phosphorus dynamics may either involve a somewhat higher rate of enzymatic conversion of organic to ortho phosphorus; a lower rate of uptake of OP within the algal turf; or there is a greater rate of settling of particulate organic phosphorus; or perhaps a combination of these[8].

Organic and Polyphosphate Phosphorus

A small percentage of the total phosphorus was documented as organic and polyphosphate phosphorus (OPP), calculated as the difference between TP and OP -- 18% for the average influent TP for the project term; 16.1% for the average SF1 effluent TP for the project term; and 15.1% of the average SF2 effluent TP for the project term. The average influent OPP is calculated as 0.046 mg/L for the project term, with the SF1 and SF2 effluent concentrations at 0.037mg/L and 0.035 mg/L respectively. The reduction therefore of 0.009 mg/L for SF1 and 0.011 mg/L for SF2 represents 34.6% and 50.0% of the total phosphorus concentration reduction, indicating that there was possibly some transformation of OPP into OP; that precipitation/sedimentation may have substantially contributed to phosphorus removal; or that both processes were involved.

[8] Note that total phosphorus is collected as a composite sample, while ortho phosphorus is collected as a grab sample, so comparison of the two must be recognized as indicative but not conclusive.

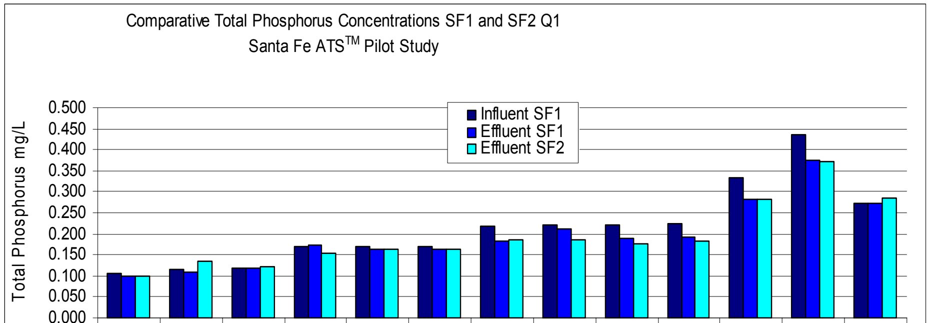
Table 11: Total Phosphorus Reduction Summary for Floways SF1 and SF2 Q1 through Q4

Quarter	Floway	Average Influent TP mg/l	Maximum Influent TP mg/L	Minimum Influent TP mg/L	Standard Deviation mg/L	Average Effluent TP mg/L	Maximum Effluent TP mg/L	Minimum Influent TP mg/L	Standard Deviation mg/L	Water Quality Based Percent Removal	Harvest Based Percent Removal
Q1	SF1	0.214 [9]	0.435	0.107	0.092	0.195	0.375	0.100	0.077	8.17	5.21
	SF2					0.193	0.373	0.099	0.076	9.68	9.89
Q2	SF1	0.300	0.377	0.249	0.046	0.254	0.329	0.202	0.033	15.45	7.02
	SF2					0.255	0.348	0.220	0.033	15.08	5.31
Q3	SF1	0.252	0.318	0.201	0.054	0.240	0.345	0.177	0.058	5.00	6.14
	SF2					0.243	0.352	0.174	0.062	3.75	5.69
Q4	SF1	0.250	0.444	0.166	0.076	0.223	0.275	0.153	0.039	7.04	2.48
	SF2					0.236	0.280	0.159	0.039	4.23	2.17
Total Project Term	SF1	0.254	0.444	0.107	0.074	0.228	0.375	0.100	0.058	9.57	5.59
	SF2					0.232	0.373	0.099	0.055	8.88	5.62

Table 12: Ortho Phosphorus Reduction Summary for Floways SF1 and SF2 Q1 through Q4

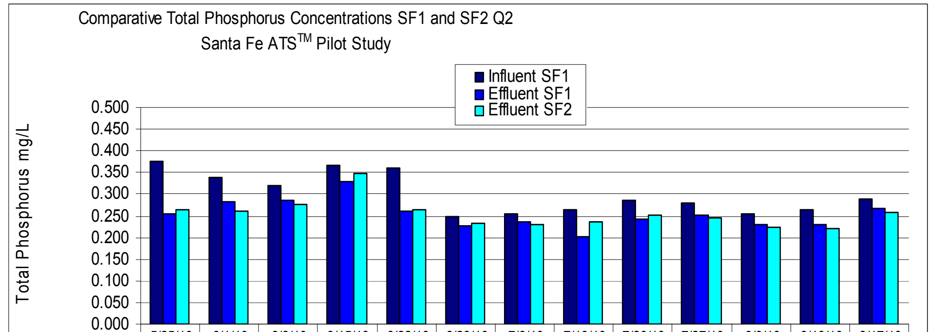
Quarter	Floway	Average Influent OP mg/l	% of TP	Maximum Influent OP mg/L	Minimum Influent OP mg/L	Standard Deviation mg/L	Average Effluent TP mg/L	% of TP	Maximum Effluent OP mg/L	Minimum Influent OP mg/L	Standard Deviation mg/L	Water Quality Based Percent Removal
Q1	SF1	0.155	72.5	0.288	0.074	0.065	0.138	70.9	0.266	0.067	0.062	11.30
	SF2						0.141	72.2	0.272	0.060	0.070	9.25
Q2	SF1	0.240	80.0	0.283	0.202	0.023	0.210	83.0	0.253	0.059	0.048	13.51
	SF2						0.227	89.3	0.255	0.198	0.020	5.93
Q3	SF1	0.223	88.0	0.263	0.183	0.031	0.209	86.8	0.254	0.152	0.031	6.01
	SF2						0.208	86.5	0.267	0.163	0.030	6.20
Q4	SF1	0.210	84.0	0.321	0.161	0.052	0.208	93.5	0.300	0.146	0.053	0.18
	SF2						0.210	88.9	0.335	0.146	0.053	-0.32
Total Project Term	SF1	0.208	82.0	0.321	0.074	0.054	0.191	83.9	0.330	0.059	0.057	8.30
	SF2						0.197	84.9	0.355	0.060	0.057	5.40

[9] For the first two weeks the influent flow and water quality was taken at both SF1 and SF2. These values were statistically indistinguishable; therefore an average of the two was taken and used as a common influent value for both floways for those two weeks. Only one influent sample was taken for subsequent weeks.



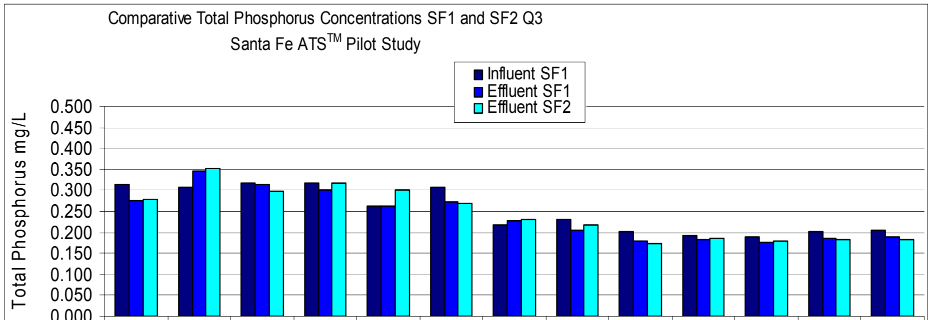
	2/23/10	3/2/10	3/9/10	3/16/10	3/23/10	3/30/10	4/6/10	4/13/10	4/20/10	4/27/10	5/4/10	5/11/10	5/18/10
Influent SF1	0.107	0.115	0.117	0.170	0.169	0.169	0.218	0.222	0.221	0.225	0.333	0.435	0.271
Effluent SF1	0.100	0.109	0.119	0.174	0.163	0.163	0.183	0.213	0.189	0.193	0.283	0.375	0.272
Effluent SF2	0.099	0.135	0.122	0.155	0.164	0.164	0.186	0.187	0.177	0.183	0.281	0.373	0.285

Week Ending



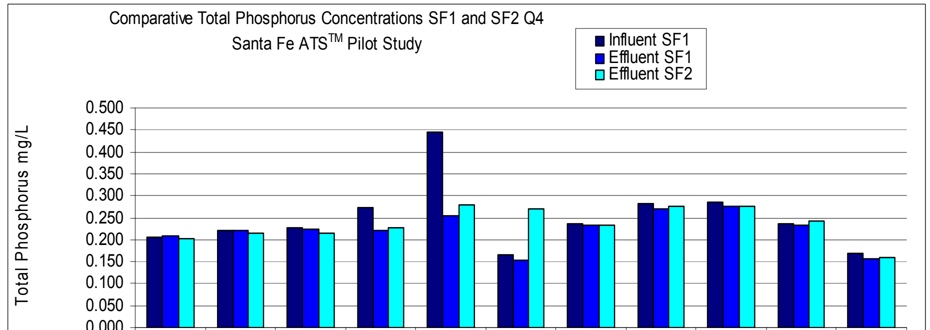
	5/25/10	6/1/10	6/8/10	6/15/10	6/22/10	6/29/10	7/6/10	7/13/10	7/20/10	7/27/10	8/3/10	8/10/10	8/17/10
Influent SF1	0.377	0.340	0.319	0.366	0.359	0.249	0.255	0.265	0.285	0.281	0.256	0.263	0.288
Effluent SF1	0.254	0.282	0.287	0.329	0.260	0.227	0.237	0.202	0.241	0.253	0.229	0.230	0.266
Effluent SF2	0.263	0.262	0.276	0.348	0.264	0.232	0.229	0.235	0.251	0.245	0.224	0.222	0.259

Week Ending



	8/24/10	8/31/10	9/7/10	9/14/10	9/21/10	9/28/10	10/5/10	10/12/10	10/19/10	10/26/10	11/2/10	11/9/10	11/16/10
Influent SF1	0.314	0.308	0.318	0.318	0.264	0.308	0.219	0.232	0.202	0.191	0.189	0.201	0.206
Effluent SF1	0.276	0.345	0.315	0.301	0.263	0.274	0.229	0.205	0.181	0.184	0.177	0.185	0.190
Effluent SF2	0.278	0.352	0.297	0.316	0.302	0.268	0.230	0.217	0.174	0.185	0.178	0.183	0.184

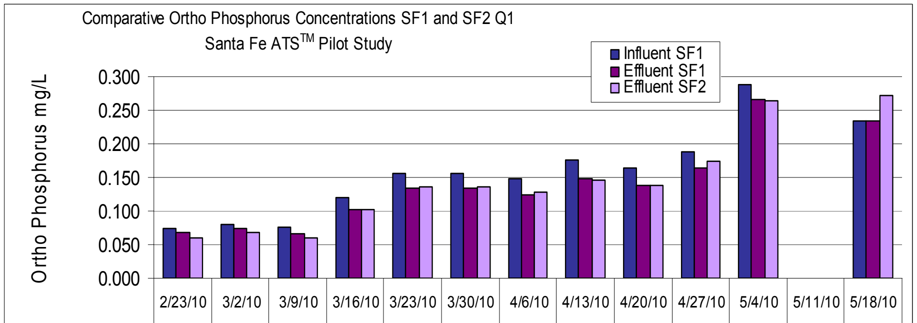
Week Ending



	11/23/10	11/30/10	12/7/10	12/14/10	12/21/10	1/18/2011	1/25/2011	2/1/2011	2/8/2011	2/15/2011	2/22/2011
Influent SF1	0.207	0.222	0.227	0.272	0.444	0.165	0.236	0.282	0.286	0.236	0.168
Effluent SF1	0.208	0.222	0.223	0.221	0.254	0.153	0.233	0.270	0.275	0.233	0.157
Effluent SF2	0.201	0.216	0.214	0.228	0.280	0.270	0.232	0.275	0.276	0.243	0.159

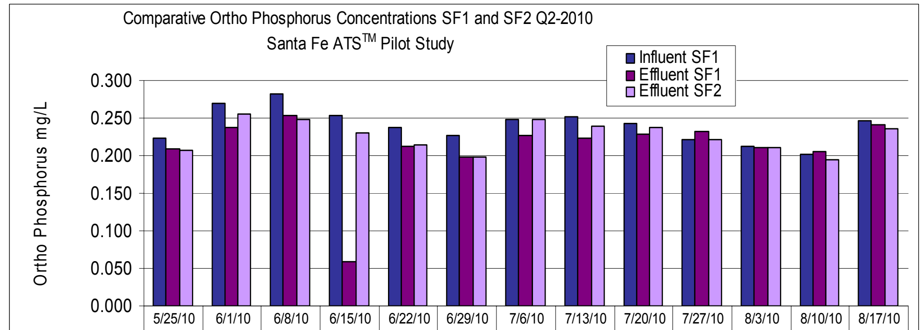
Week Ending

Figure 25: Influent and Effluent Total Phosphorus Concentrations for Floways SF1 and SF2 during Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program



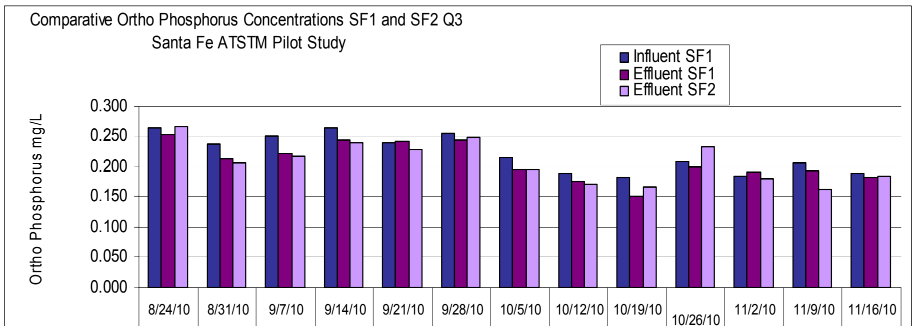
	2/23/10	3/2/10	3/9/10	3/16/10	3/23/10	3/30/10	4/6/10	4/13/10	4/20/10	4/27/10	5/4/10	5/11/10	5/18/10
Influent SF1	0.074	0.080	0.077	0.120	0.157	0.157	0.149	0.176	0.164	0.188	0.288		0.235
Effluent SF1	0.069	0.074	0.067	0.103	0.135	0.135	0.124	0.149	0.138	0.165	0.266		0.235
Effluent SF2	0.060	0.068	0.061	0.103	0.137	0.137	0.128	0.146	0.138	0.175	0.265		0.272

Week Ending



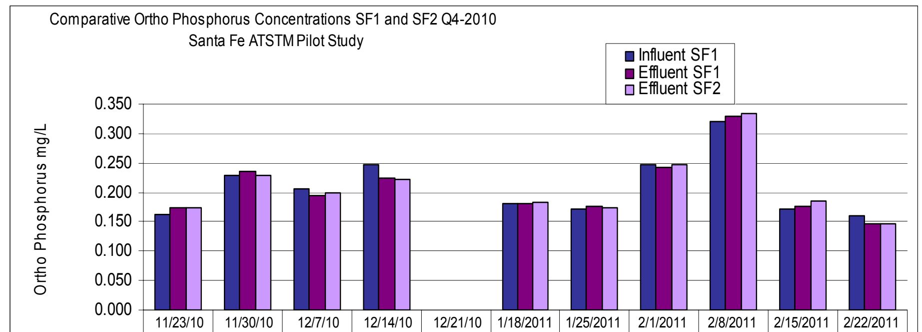
	5/25/10	6/1/10	6/8/10	6/15/10	6/22/10	6/29/10	7/6/10	7/13/10	7/20/10	7/27/10	8/3/10	8/10/10	8/17/10
Influent SF1	0.223	0.270	0.283	0.254	0.238	0.226	0.249	0.252	0.243	0.221	0.213	0.202	0.246
Effluent SF1	0.209	0.237	0.253	0.059	0.212	0.199	0.226	0.224	0.228	0.232	0.210	0.205	0.241
Effluent SF2	0.208	0.255	0.248	0.231	0.215	0.198	0.249	0.240	0.238	0.222	0.211	0.194	0.236

Week Ending



	8/24/10	8/31/10	9/7/10	9/14/10	9/21/10	9/28/10	10/5/10	10/12/10	10/19/10	10/26/10	11/2/10	11/9/10	11/16/10
Influent SF1	0.264	0.238	0.252	0.265	0.240	0.256	0.215	0.190	0.183	0.210	0.185	0.207	0.188
Effluent SF1	0.254	0.214	0.223	0.245	0.242	0.244	0.195	0.176	0.152	0.201	0.192	0.193	0.182
Effluent SF2	0.267	0.207	0.217	0.241	0.229	0.248	0.195	0.172	0.167	0.234	0.179	0.163	0.184

Week Ending



	11/23/10	11/30/10	12/7/10	12/14/10	12/21/10	1/18/2011	1/25/2011	2/1/2011	2/8/2011	2/15/2011	2/22/2011
Influent SF1	0.162	0.228	0.205	0.247		0.181	0.172	0.247	0.321	0.172	0.160
Effluent SF1	0.175	0.236	0.194	0.225		0.180	0.176	0.243	0.330	0.176	0.146
Effluent SF2	0.175	0.228	0.199	0.221		0.183	0.175	0.247	0.335	0.186	0.146

Week Ending

Figure 26: Influent and Effluent Ortho Phosphorus Concentrations for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

Phosphorus Mass Removal and Areal Removal Rates

As noted in Figure 27, for the period through Q1, total phosphorus mass removal for the water quality based and harvest based calculations tracked rather closely for SF1 and SF2, and the two floways also showed similar trends. However, during Q2 a substantial divergence between the mass removals as calculated by harvest and as calculated through water quality data was noted for both floways, with the water quality based values being the higher (452 g Vs. 206 g for SF1 and 442 g Vs. 156 g for SF2). During Q3 the two again converged, and the total phosphorus removal calculated through water quality (119 g for SF1 and 87 g for SF2) was lower than that calculated through harvest (157 g for SF1 and 145 g for SF2). For Q4, another divergence was recorded, with the water quality based removal being 118 g for SF1 and 70 g for SF2, and the harvest based removal being 42 g for SF1 and 36 g for SF2. Overall, the calculated removal as calculated through water quality was considerably higher than that calculated using harvest data. Such variation has been observed with other ATS™ programs[10], and may be attributable to both the lower reliability of harvest based data, and periods of external loss of phosphorus through phenomenon such as sloughing and escaped harvest, hatching and emigration of insect pupae, and grazing and predation by immigrating and visiting organisms.

For Q1, as with mass removals, total phosphorus areal removal rates (ARR) for the water quality based and harvest based calculations tracked rather closely for SF1 and SF2, diverged through the Q2 period, but converged again through Q3, then diverged again during Q4 as noted in Figure 28. The two floways showed similar trends throughout the four quarter period. The total phosphorus ARR, based upon water quality data, for the project period were 18.91 g/m^2-year and 17.56 g/m^2-yr for SF1 and SF2, respectively, and based upon harvest data, 11.05 g/m^2-year and 11.11 g/m^2-yr for SF1 and SF2, respectively. These total phosphorus areal removal rates exceed typical performance for a fully operational and maintained treatment wetland system operating under similar water quality conditions. Such a treatment wetland system would be expected to provide phosphorus areal removal rates of <1.5 to 3 g/m^2-year.

For Q1, ortho-phosphorus mass removal and areal removal rates (ARR) for the water quality based calculations tracked rather closely for SF1 and SF2[11] (Figures 29 and 30), with some divergence noted during Q2, with SF1 ortho phosphorus ARR being notably higher than that of SF2. During Q3 the ortho-phosphorus ARR decreased from the Q2 values. This may be due to an outlier effluent value on 6/15/10 of 0.059 mg/L, which was considerably lower than other data. During Q4 there was a dramatic drop in the ortho-phosphorus ARR to 0.26 g/m^2-year for SF1 and -0.42 g/m^2-year for SF2. This was due likely to low water temperatures, low NOx-N and the corresponding low productivity, as well as the disruptions associated with the shut down period from 12/21/10 to 1/11/11. The cumulative ortho-phosphorus ARR values for the monitoring period of Q1 through Q4 were 12.50 g/m^2-year for SF1 and 8.61 g/m^2-year for SF2.

[10] HydroMentia (2005) "S-154 Pilot ATS™-WHS™ Aquatic Plant Treatment System Final Report" for SFWMD Contract C-13933

[11] Note that Ortho P was not determined on the harvested tissue

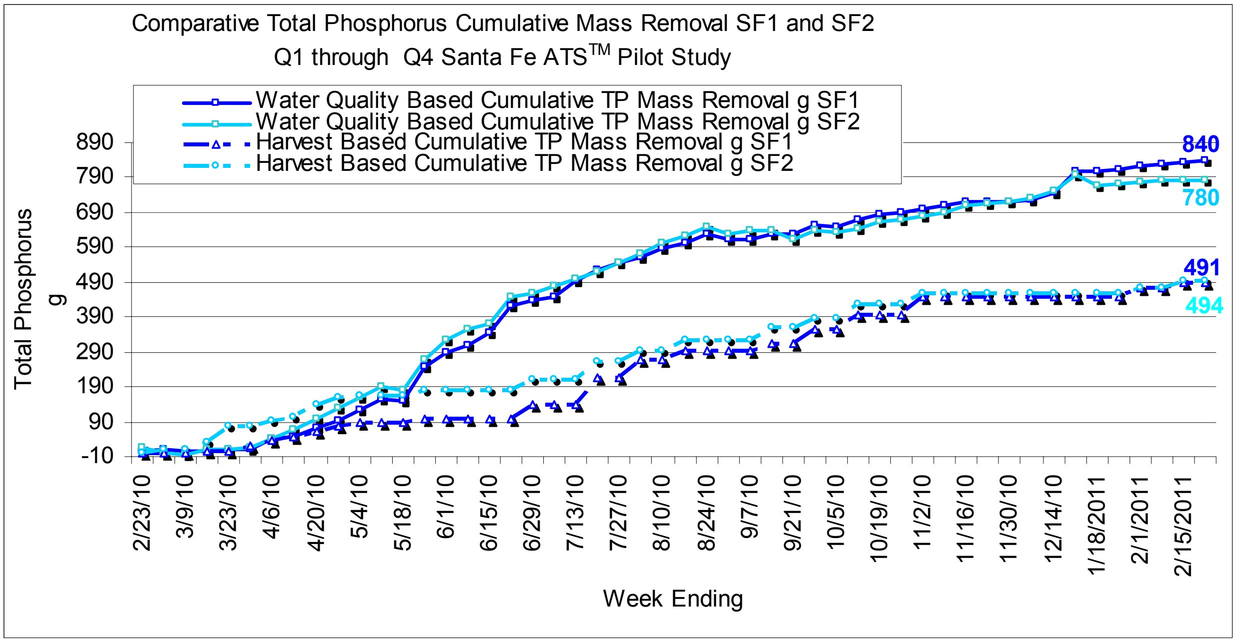


Figure 27: Total Phosphorus Mass Removal for Floways SF1 and SF2 during Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

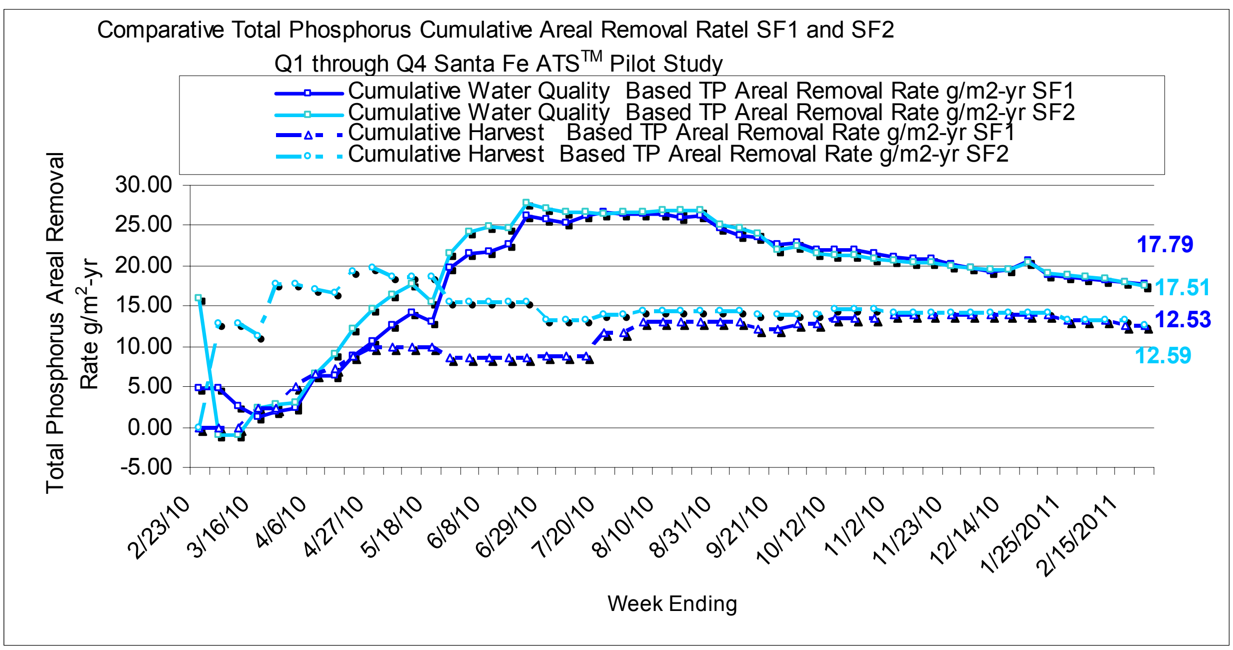


Figure 28: Total Phosphorus Areal Removal Rates for Floways SF1 and SF2 during Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

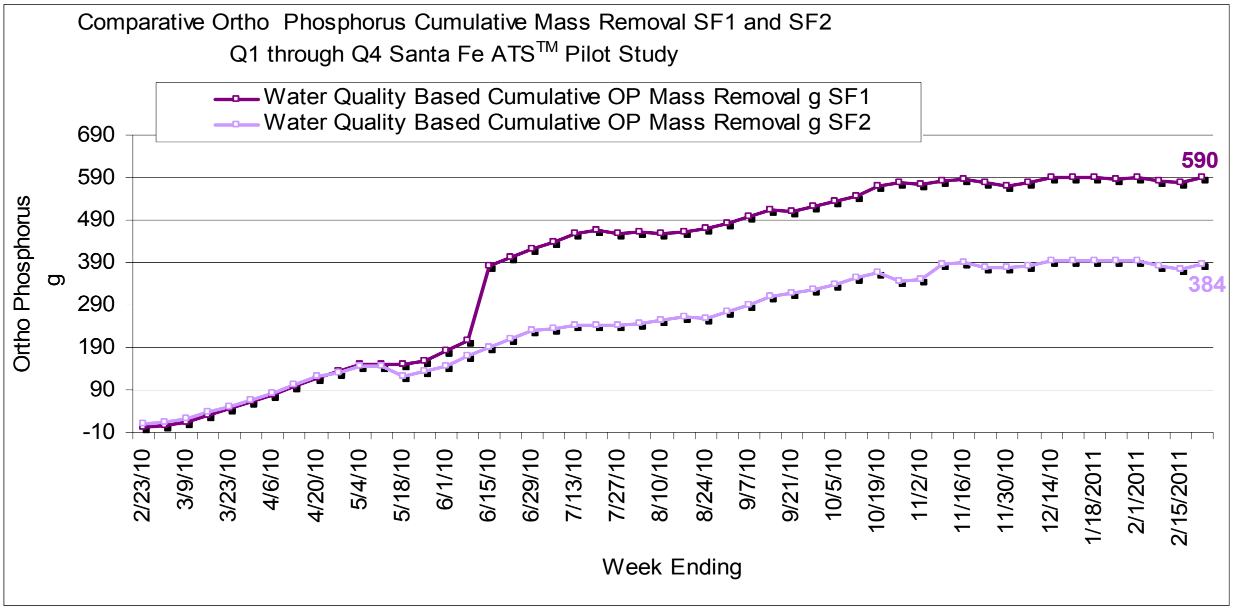


Figure 29: Ortho Phosphorus Mass Removal for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

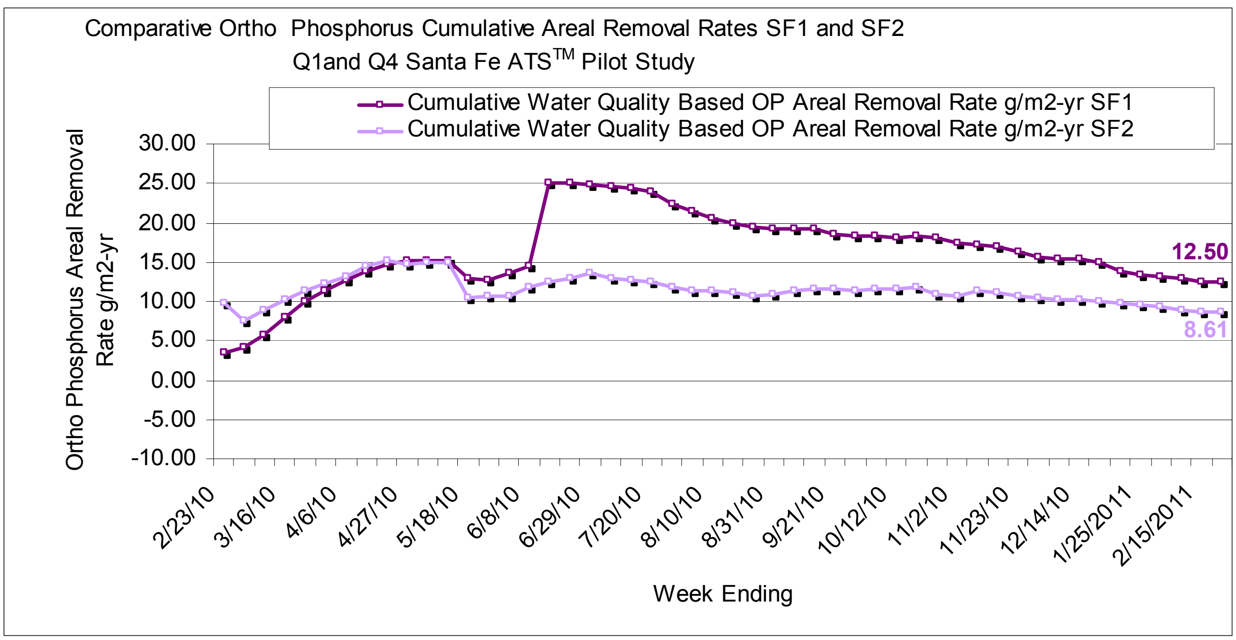


Figure 30: Ortho Phosphorus Areal Removal Rates for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

Other Water Quality Considerations

pH and Alkalinity

Typically, when algal turf productivity is active, an upward daytime shift in pH is noted from influent to effluent. The extent of this pH shift is largely dependent upon the initial pH and alkalinity, as well as the productivity level. The higher the alkalinity and the lower the initial pH the more attenuated the differential. During the nighttime, when respiration dominates, CO_2 levels recover, and pH shifts downward. These patterns result in diurnal pH fluctuations which are typical of ATS™ dynamics (Figure 31). During Q1, pH was taken during the daytime (usually 9:00 -10:00 AM) from the influent and effluent of both floways. The upward pH shift from an average influent pH of 6.63 to an average effluent pH of 7.80 for SF1 and 7.91 for SF2 reflects the consumption of carbon dioxide and bicarbonate and carbonate alkalinity, and the generation of hydroxyl alkalinity. During Q2, the influent pH shifted upward to an average of 7.20, with the average effluent at 8.40 for SF1 and 8.47 for SF2. During Q3 the influent pH was even higher at 7.38, with the effluent pH at 8.02 for SF1 and 8.12 for SF2, and during Q4 the influent pH dropped substantially to an average influent of 6.94 to an effluent pH of 7.80 for both SF1 and SF2. For the project term, the influent pH averaged 7.08 with the SF1 effluent pH at 8.08 and the SF2 effluent pH at 8.17 (Table 13 and Figure 32).

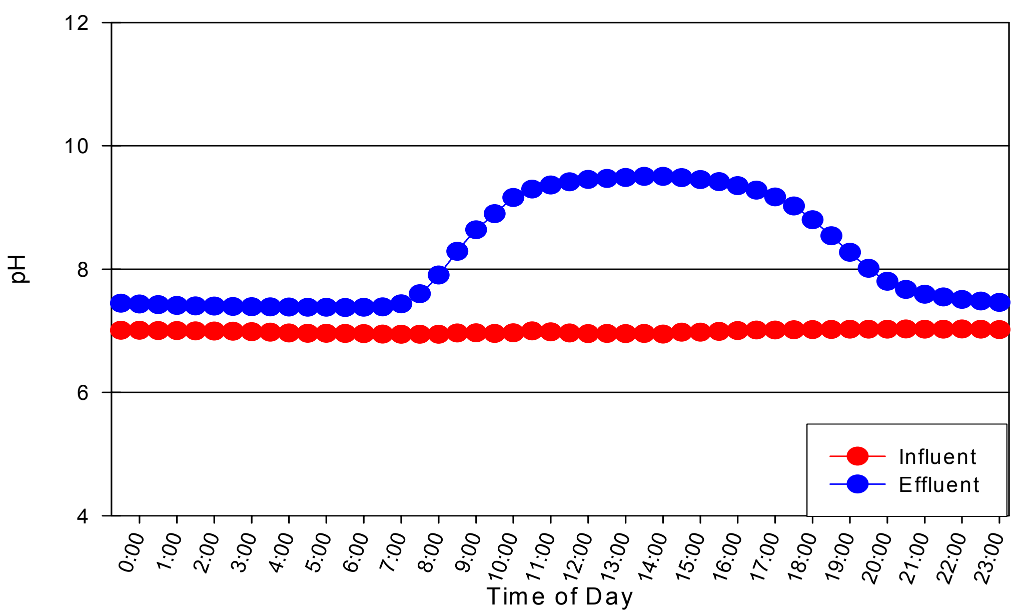


Figure 31: Typical Diurnal pH Trends Across an Active ATS™ floway [12]

Santa Fe River water is a soft, low alkalinity, highly colored surface water with comparatively low mineral content. Its low alkalinity and high color indicate the source of its flow is largely from surface runoff and shallow groundwater seepage associated with the contiguous hardwood and cypress forests along the floodplain as well as the up gradient watershed. As the Santa Fe confluences with the Suwannee River (about 22 miles downstream from the pilot system site), artesian springs (e.g. Itchetucknee Spring) emanating from the Floridan Aquifer contribute significant flow to the rivers, and accordingly alkalinity increases and color levels can fluctuate seasonally to a greater extent.

[12] Taken from Hydromentia (2005) "S-154 Pilot ATS™-WHS™ Aquatic Plant Treatment System Final Report" for SFWMD Contract C-13933

As noted from Table 13 and Figure 32, the pH trends for both floways were very similar throughout the project term, and are typical of daytime patterns. While the alkalinity is low, the initial pH during Q1 was on the acidic side of neutral, which means the solubility of CO_2 is comparatively high. The presence of abundant CO_2 not only ensures adequate carbon is available during photosynthesis, but also the rate of pH increase is attenuated. During Q2 however, a pH shift upward was documented within the influent water, which correlates with lower levels of available carbon, and lower CO_2 solubility. Therefore the algae relied more upon internal carbon sources (bicarbonate and carbonate), and less upon atmospheric sources. Therefore effluent pH levels were higher. During Q3 alkalinity levels were noted to be somewhat higher, but influent pH levels were also higher, so the net influence upon available influent carbon was similar to Q2. However, effluent pH levels were lower during Q3 when compared to Q2, which corresponds with lower Q3 productivity. During Q4 influent pH was again comparatively low (6.94), and the productivity was low, likely due to low water temperatures and a paucity of available nitrogen. Therefore carbon consumption was low, and the pH shift was not as dramatic, with the effluent levels at 7.80.

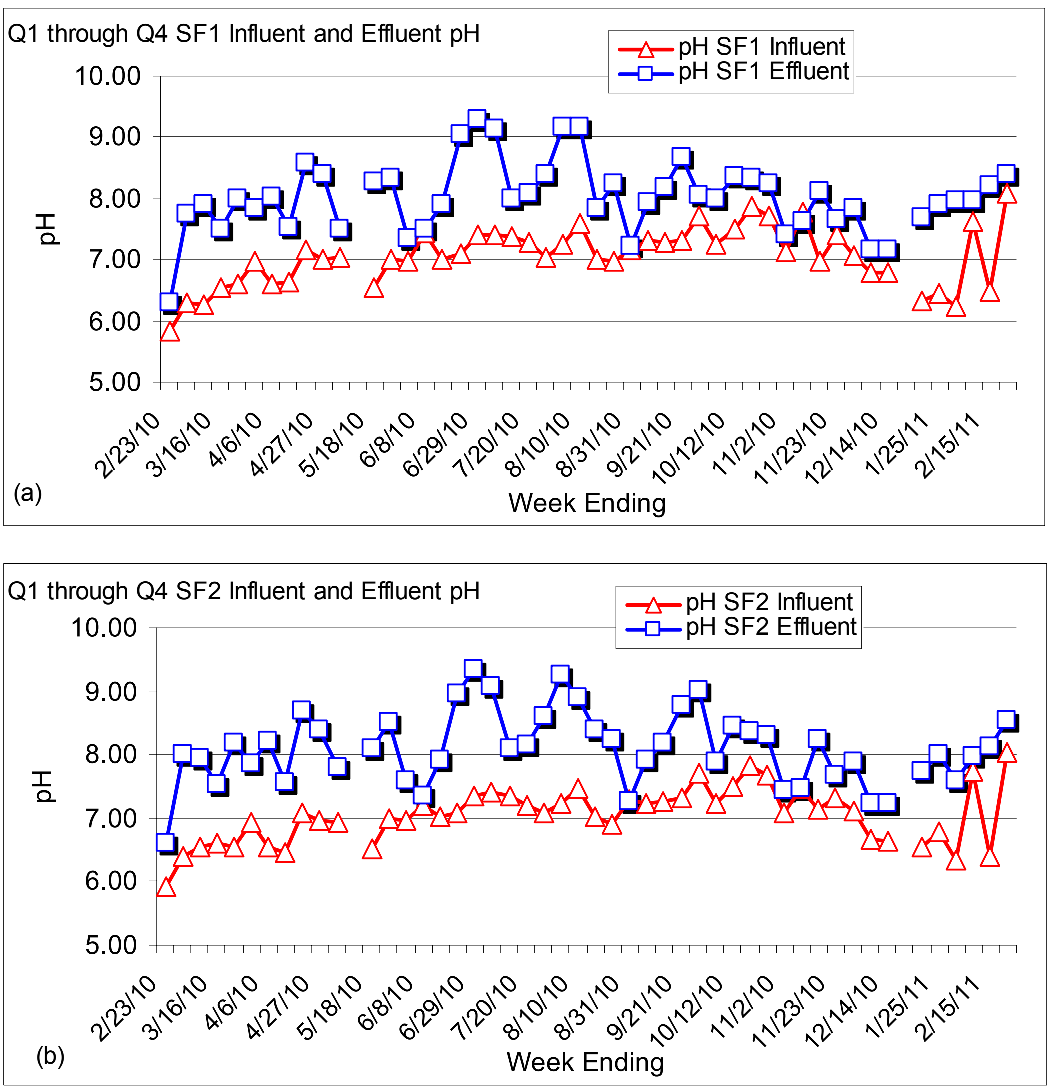


Figure 32: Daytime pH Trends for Floways SF1 (a) and SF2 (b) during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

Table 13: Daytime pH, DO, Water Temperature and Conductivity for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

		pH				Dissolved Oxygen mg/L				Water Temperature °C				Conductivity microS/cm			
		SF1		SF2		SF1		SF2		SF1		SF2		SF1		SF2	
Date	Time	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
2/23/10	13:50	5.83	6.29	5.92	6.61	9.71	10.60	10.40	11.64	15.00	20.80	15.06	20.33	75	85	76	82
3/2/10	9:05	6.31	7.74	6.41	8.01	11.44	13.08	11.60	13.12	11.50	17.46	11.37	17.03	78	83	77	83
3/9/10	9:10	6.26	7.91	6.55	7.95	9.18	11.52	11.96	12.92	11.98	13.21	11.96	12.92	77	75	77	76
3/16/10	9:20	6.54	7.51	6.62	7.54	8.10	11.23	13.13	13.43	14.10	14.11	13.13	13.41	84	78	84	77
3/23/10	9:20	6.60	8.00	6.56	8.17	8.75	11.92	8.69	12.99	13.57	14.26	13.6	14.46	72	69	72	70
3/30/10	9:20	6.97	7.84	6.93	7.87	7.70	11.70	7.60	12.07	15.83	15.18	15.83	15.38	90	84	90	85
4/6/10	9:30	6.61	8.04	6.54	8.21	7.70	11.77	7.60	12.07	18.94	21.46	18.95	21.18	87	85	87	86
4/13/10	8:36	6.63	7.54	6.47	7.55	7.70	11.14	7.99	11.29	18.26	18.28	18.29	18.48	90	84	90	86
4/20/10	8:45	7.16	8.57	7.07	8.7	7.69	11.89	7.50	12.01	19.63	19.56	18.64	19.53	107	104	107	101
4/27/10	8:48	7.01	8.38	6.95	8.4	6.91	11.22	7.02	11.35	20.23	21.02	20.23	21.07	114	108	114	108
5/4/10	8:50	7.05	7.50	6.92	7.81	5.91	7.93	6.04	8.42	23.92	25.17	23.91	25.01	93	87	92	80
5/11/10	POWER OUTAGE																
5/18/10	9:50	6.53	8.28	6.52	8.11	6.43	8.03	6.37	8.20	24.21	27.22	24.2	26.74	107	107	107	107
5/25/10	8:25	7.02	8.34	6.98	8.52	5.88	8.15	6.09	8.83	24.03	24.00	24.01	24.01	117	110	117	110
6/1/10	8:50	6.98	7.36	6.97	7.58	7.65	9.02	7.65	9.35	23.96	26.10	23.96	26.41	127	127	127	127
6/8/10	8:57	7.43	7.51	7.2	7.35	5.64	7.21	5.63	7.49	25.47	27.34	25.47	27.34	127	127	108	107
6/15/10	9:15	7.01	7.90	7.02	7.92	5.29	9.59	5.42	9.35	28.18	30.17	28.17	30.6	130	129	130	130
6/22/10	9:30	7.11	9.03	7.09	8.95	6.07	6.14	6.14	11.27	25.40	27.47	25.39	27.69	128	128	128	124
6/29/10	9:45	7.42	9.30	7.35	9.36	5.48	12.09	5.72	12.78	27.27	29.04	27.25	28.95	124	124	124	124
7/6/10	9:20	7.41	9.14	7.4	9.07	5.79	12.06	5.85	12.16	24.97	26.18	24.98	26.19	127	127	128	127
7/13/10	9:00	7.38	7.99	7.35	8.1	6.66	11.56	6.58	12.15	25.82	28.10	25.82	28.4	83	74	82	76
7/20/10	9:10	7.29	8.09	7.19	8.16	5.85	9.11	5.45	9.20	27.25	29.84	27.24	30.01	104	102	104	102
7/27/10	9:25	7.05	8.38	7.08	8.59	4.95	10.51	4.38	11.93	28.61	30.61	27.92	30.31	118	113	124	120
8/3/10	9:30	7.24	9.17	7.22	9.27	4.85	11.24	5.01	10.64	27.95	30.31	28.6	30.75	125	121	119	115
8/10/10	9:10	7.58	9.17	7.46	8.9	7.32	15.15	7.94	14.32	26.62	30.01	26.62	30.05	115	111	115	111
8/17/10	9:40	7.00	7.84	7.03	8.4	7.94	14.32	5.32	9.22	27.30	30.61	27.31	30.91	117	121	118	118
8/24/10	0:00	6.98	8.24	6.89	8.24	5.77	10.44	5.37	10.48	26.57	27.75	26.58	27.79	91	90	91	89
8/31/10	0:00	7.16	7.21	7.28	7.26	5.97	6.68	5.37	5.58	25.01	27.45	25.01	27.45	83	82	82	79
9/7/10	0:00	7.30	7.92	7.24	7.91	6.56	7.58	6.32	7.37	25.60	27.83	25.03	27.97	102	94	102	100
9/14/10	0:00	7.27	8.18	7.27	8.18	5.89	10.40	5.98	10.73	26.35	28.28	26.36	28.44	115	110	115	112
9/21/10	0:00	7.30	8.67	7.32	8.78	6.59	13.34	6.56	13.34	24.63	25.37	24.62	25.36	137	133	137	133
9/28/10	0:00	7.72	8.06	7.7	9.01	5.46	11.44	5.13	11.24	24.33	25.46	24.22	25.46	135	130	135	128
10/5/10	0:00	7.25	7.98	7.23	7.89	6.37	11.46	6.14	11.60	20.11	20.45	20.17	20.31	138	133	138	133
10/12/10	0:00	7.49	8.36	7.51	8.45	7.57	8.45	6.61	12.64	19.66	21.49	19.69	21.66	142	142	142	142
10/19/10	0:00	7.87	8.33	7.82	8.36	8.04	16.39	8.32	15.73	17.14	19.30	17.16	19.4	137	136	137	137
10/26/10	0:00	7.71	8.24	7.69	8.29	5.54	11.20	5.16	11.31	19.89	23.79	19.92	24.09	146	154	146	154
11/2/10	0:00	7.13	7.41	7.09	7.43	4.05	9.74	4.38	9.86	17.91	18.50	17.91	18.58	141	140	141	140
11/9/10	0:00	7.79	7.61	7.47	7.48	8.08	16.22	7.31	10.00	11.78	15.46	11.84	14.95	124	124	124	132
11/16/10	9:40	6.97	8.11	7.15	8.24	6.97	8.11	7.15	8.24	14.15	17.20	14.17	18	131	131	131	137
11/23/10	10:10	7.42	7.66	7.33	7.68	6.27	11.77	6.19	11.81	6.19	11.81	15.38	20.97	137	147	135	149
11/30/10	10:10	7.08	7.85	7.1	7.89	4.86	11.92	4.78	11.88	17.21	21.01	17.33	21.05	142	149	143	152
12/7/10	10:10	6.80	7.17	6.67	7.24	6.24	13.90	6.48	13.09	7.62	11.10	7.53	9.87	109	114	111	106
12/14/10	10:25	6.80	7.17	6.64	7.24	6.24	13.90	6.48	13.09	7.62	11.10	7.53	9.87	109	114	111	106
12/21/10	NO FLOW																
1/18/11	10:20	6.34	7.70	6.55	7.73	10.47	10.88	10.61	10.92	9.97	13.06	10.03	13.08	136	147	137	101
1/25/11	10:30	6.44	7.90	6.8	8.01	11.09	15.84	11.60	16.02	10.87	14.16	10.23	13.88	140	142	145	139
2/1/11	10:30	6.24	7.96	6.34	7.58	11.41	17.27	11.60	16.37	12.48	13.69	12.45	13.57	149	136	150	156
2/8/11	10:30	7.62	7.95	7.73	7.98	9.67	14.15	9.68	14.01	11.60	11.21	11.56	11.31	101	96	101	95
2/15/11	10:30	6.47	8.20	6.41	8.13	9.89	13.26	10.05	12.94	10.45	15.96	10.43	16.03	100	110	99	103
2/1/11	10:20	8.08	8.40	8.05	8.53	7.41	12.19	7.46	11.40	17.56	20.13	17.54	20.17	136	136	135	138
Q1 Averages		**6.63**	**7.80**	**6.62**	**7.91**	**8.10**	**11.00**	**8.83**	**11.63**	**17.26**	**18.98**	**17.10**	**18.80**	**90**	**87**	**89**	**87**
Q2 Averages		**7.22**	**8.40**	**7.18**	**8.47**	**6.11**	**10.47**	**5.94**	**10.67**	**26.37**	**28.44**	**26.36**	**28.59**	**119**	**116**	**117**	**115**
Q3 Averages		**7.38**	**8.02**	**7.36**	**8.12**	**6.37**	**10.88**	**6.14**	**10.62**	**21.01**	**22.95**	**20.98**	**23.04**	**125**	**123**	**125**	**124**
Q4 Averages		**6.93**	**7.80**	**6.96**	**7.80**	**8.36**	**13.51**	**8.49**	**13.15**	**11.16**	**14.32**	**12.00**	**14.98**	**126**	**129**	**127**	**125**
Project Term Averages		**7.09**	**8.08**	**7.06**	**8.17**	**6.83**	**10.78**	**6.92**	**10.96**	**21.66**	**23.57**	**21.59**	**23.60**	**112**	**110**	**111**	**109**

Because of the low alkalinity in the Santa Fe River near Boston Farm, carbon may at times be limited down the floway, resulting in reduced nitrogen and phosphorus removal rates due to reduced algal turf productivity. Because of this reduced productivity, pH levels within the effluent did not elevate to levels above 9.00. However, it is not unusual for pH levels associated with a low alkalinity ATS™ effluent to approach 10 once bicarbonate and carbonate alkalinity is consumed. At such high pH levels, it becomes unclear whether productivity diminishes in response to carbon availability or the potential toxicity of the high pH. It is quite likely that both phenomenon factor into the attenuation of production.

The alkalinity within the Santa Fe River at the influent intake was comparatively low, averaging about 32 mg/L as $CaCO_3$ during the Q1 through Q4 monitoring period. The relationship of pH and alkalinity to available carbon for algal photosynthesis was investigated by Saunders et al.[13]. The available carbon was expressed as a percentage of total alkalinity, as noted in Figure 33.

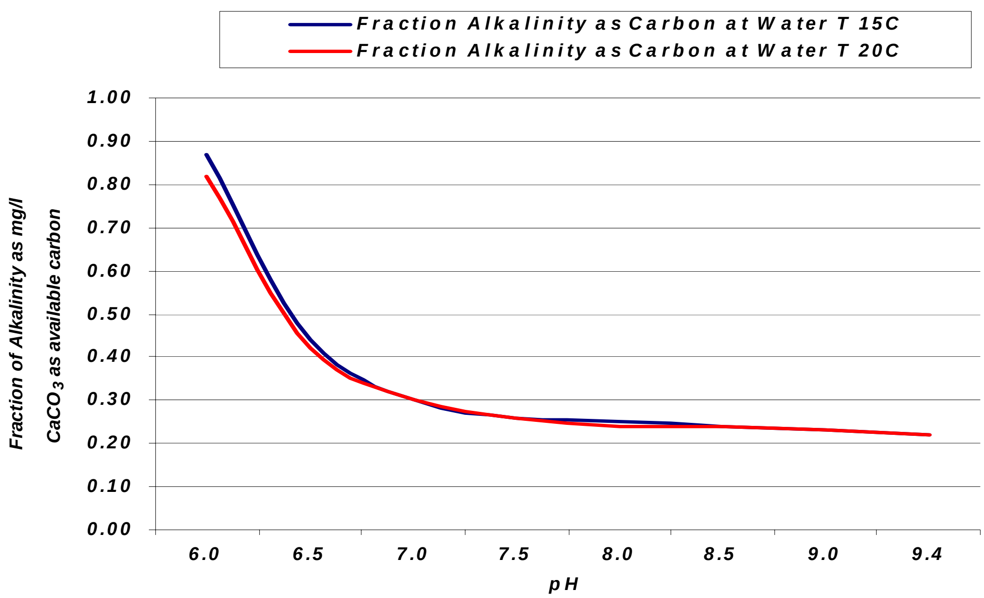


Figure 33: Available Carbon, Alkalinity, pH relationship per Saunders et. al. [14]

It is reasonable to make rough estimates of the amount of available carbon consumed by the algal turf community from influent and effluent pH and alkalinity data, using the relationship expressed in Figure 33, recognizing that other factors may also influence pH. Such an estimate is presented in Table 14. As shown, the percentage of gross productivity which results in a net community production was much lower during Q1 than Q2 or Q3, suggesting that perhaps during the start up period there is considerable energy invested in establishing a quasi-stable community. During Q2 and Q3, the percentage of gross productivity which results in net productivity increased considerably, indicating the system may now be investing more energy into a standing crop. This is important, as it is largely the viable standing crop which drives the nutrient removal rates. Attendant with this increase in the percentage of gross primary productivity invested in net community productivity was a general increase in tissue nutrient content, as noted in Section 2. During Q4, the ratio as with Q1, is very low, indicating considerable energy investment

[13] Saunders, G.W., F.B. Trama, and R.W. Bachman. 1962. Evaluation of a modified C14 technique for shipboard estimation of photosynthesis in large lakes. Great Lakes Research Division, Institute of Science and Technology, University of Michigan, Ann Arbor, Michigan, USA.

[14] Saunders, G.W., F.B. Trama, and R.W. Bachman. 1962. Evaluation of a modified C14 technique for shipboard estimation of photosynthesis in large lakes. Great Lakes Research Division, Institute of Science and Technology, University of Michigan, Ann Arbor, Michigan, USA.

in sustaining or reestablishing the crop under stressful conditions—low, intermittent flows; low temperatures; and low nitrate levels.

It is noteworthy that downstream within the Suwannee River system, increases in both alkalinity (and available carbon) and NOx-N are substantial. Alkalinity levels in the Middle and Lower Suwannee River are typically 120 to 140 mg/l as $CaCO_3$ or higher, providing significantly greater carbon availability.

It is well documented in ATS™ systems that low available carbon and low available nitrogen can reduce algal productivity. Higher alkalinities imply higher available carbon within the source water, which typically result in higher algal productivity, less pH fluctuation down the floway, and increased pollutant recovery rates.

Considering these factors, it is reasonable to expect higher rates of algal productivity and nitrogen removal rates when the ATS™ technology is applied to direct treatment of the Suwannee River. To quantify these higher rates of performance, inflow from the Santa Fe River may be augmented by the addition of sodium bicarbonate and nitrate nitrogen to emulate Suwannee River water conditions.

Table 14: Carbon Consumption and Productivity Estimates for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

Qtr/Floway	Average Alkalinity mg/L as $CaCO_3$	Total Flow Million Gallons	Influent pH	Available influent Carbon as Percent of Alkalinity	Daytime Influent Available Carbon mg/L	Effluent pH	Available Effluent Carbon as Percent of Alkalinity	Daytime Effluent Available Carbon mg/L	Carbon Consumed lb*	Tissue Percent Carbon	Estimated gross primary production dry lb	Field Measured net community production dry lb	Net/Gross Ratio
Q1/SF1	20	2.387	6.63	38.0%	7.6	7.80	25.0%	5.0	25.9	14.3	181.1	27.3	0.15
Q1/SF2	20	2.387	6.62	38.0%	7.6	7.91	24.0%	4.8	27.9	13.1	213.0	52.2	0.25
Q2/SF1	24	2.560	7.22	29.0%	7.0	8.40	22.0%	5.3	17.9	25.6	70.0	61.0	0.87
Q2/SF2	24	2.560	7.18	29.0%	7.0	8.47	21.0%	5.0	20.5	24.7	84.0	48.5	0.58
Q3/SF1	31	2.481	7.38	26.0%	8.1	8.02	23.0%	7.1	10.3	18.4	56.0	44.7	0.80
Q3/SF2	31	2.481	7.36	26.0%	8.1	8.12	22.5%	7.0	11.4	18.3	62.3	47.6	0.76
Q4/SF1	52	1.821	6.93	31.0%	16.1	7.80	25.0%	13.0	23.5	15.1	155.6	11.0	0.07
Q4/SF2	52	1.821	6.96	31.0%	16.1	7.80	25.0%	13.0	23.5	17.4	135.1	10.6	0.08

***Assume 50% daylight hour**

Dissolved Oxygen (DO)

Oxygen is a product of photosynthesis. During the daytime when photosynthesis rates are typically high, enough oxygen is generated by the ATS™ such that levels in the effluent can exceed saturation. It is not unusual for DO effluent levels to approach 14 mg/L, even during the summer when saturation concentrations can be as low as 5-6 mg/L. At night, while there is no photosynthetic DO contributed to the floway, the shallow flow associated with the ATS™ process facilitates comparatively high reaeration rates, thereby avoiding the severe DO “sag” often associated with highly productive systems. Therefore, while there is a drop in DO levels at night, they typically remain higher than the influent levels, and above 5 mg/L[15] (Figure 34).

Q1 daytime DO levels were similar for both floways, and showed the typical pattern, with effluent levels above saturation. This pattern persisted through the remaining quarters. This increase in DO is indicative of active algal turf productivity (Table 13 and Figure 35); although because of the variability of DO saturation concentrations with temperature, and the active exchange with the atmosphere, it is not practical to try to estimate production across an ATS™ based upon the change in DO levels. However, when there is a noticeable decline in the differential, and the daytime effluent concentrations approximate daytime influent concentrations, this may be indicative of a substantial drop in productivity. During the monitoring period, mean DO levels increased 60.6% for Floway SF1 from 7.1 mg/l to 11.4 mg/l, and increased 58.3% from 7.2 mg/l to 11.4 mg/l for Floway SF2.

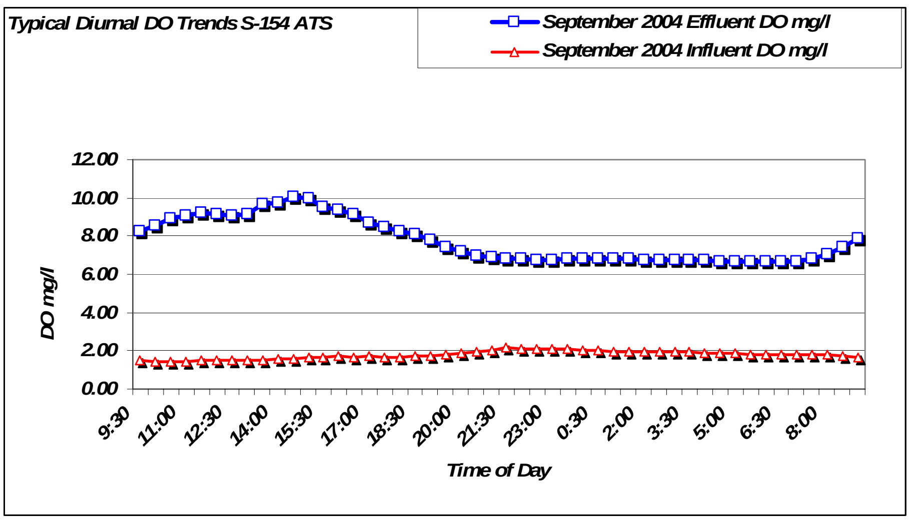
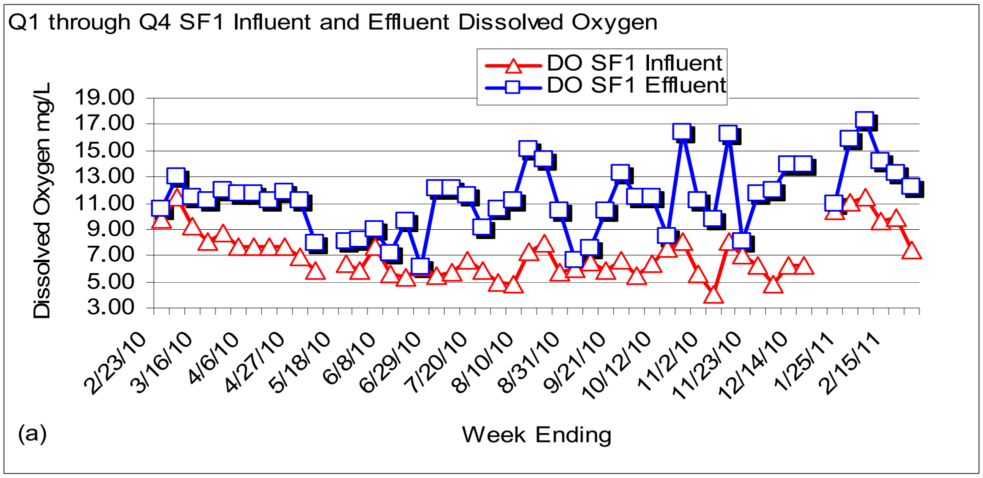


Figure 34: Typical Diurnal DO Trends Across an Active ATS™ Floway (see footnote 13**)**

At the time that the project was initially proposed, continuous monitoring of DO levels was not included. Considering that segments of the Santa Fe and Suwannee Rivers are verified as impaired for low dissolved oxygen levels, it may be beneficial in future programs to continuously monitor DO levels to allow for an accurate assessment as to how elevated DO levels in the ATS™ discharges may benefit receiving waters.

[15] The maintenance of DO levels at nighttime depends upon the amount of biodegradable organics within the water. If the level of these organics is high (> 20 mg/L BOD_5), then DO levels at night could drop to disruptive levels. Typically this is not the case with Class III surface waters in Florida.



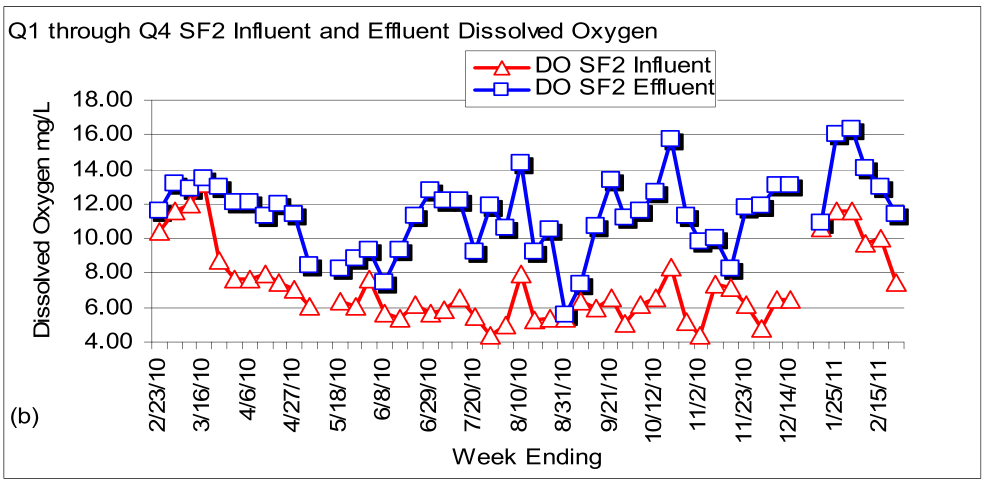


Figure 35: Daytime DO Trends for Floways SF1 (a) and SF2 (b) during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

Water Temperature

Water temperature changes from influent to effluent across an ATS™ floway depend upon the differential between air temperature and water temperature. A typical pattern for Florida when the daytime air temperature is normally higher than the water temperature is for the water to gain heat down the floway during the day time, and then release heat at night (Figure 36). The daytime water temperature changes for Q1 through Q4 reflect expected seasonal changes. The water temperature changes from influent to effluent observed across both SF1 and SF2 floways show the differential from effluent to influent being higher for Q4 than for the other quarters (1.70-1.71 °C for Q1; 2.07-2.23 °C for Q2; 1.94 -2.11°C for Q3; 3.16-2.98 °C for Q4). Daytime water temperatures during Q4 were the lowest (11.16 -12.00 °C) but showed the highest differential between influent and effluent, as noted in Table 13 and Figure 37. Increased temperature normally solicits increased algal productivity when all other factors are equal, although prolonged temperatures above 40° C have the potential of challenging the physiology of certain algal communities. It is not expected that even during peak summer, that effluent water temperature will reach 40 ° C.

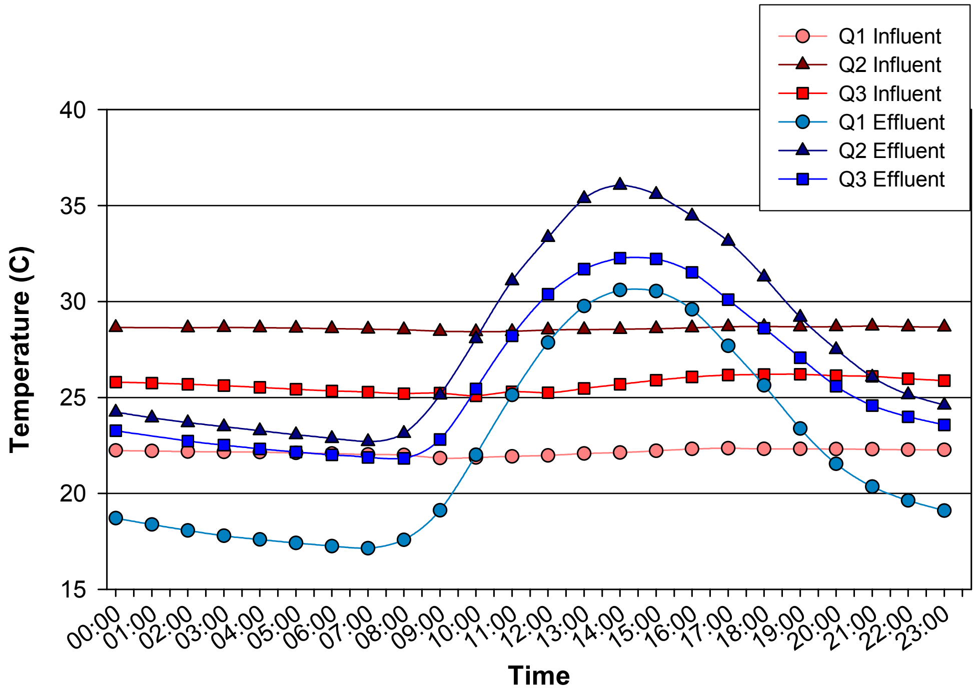
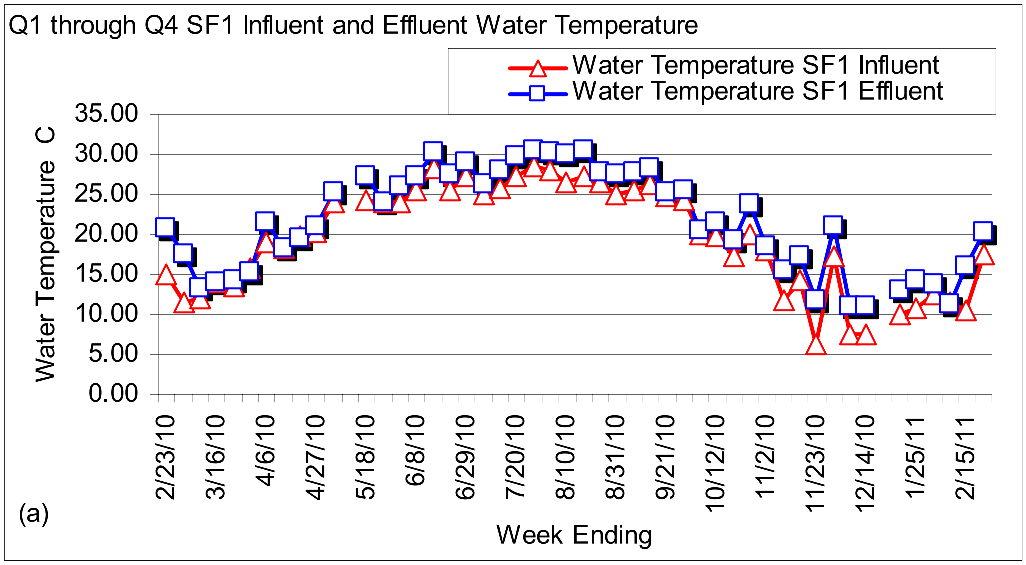


Figure 36: Typical Diurnal Water Temperature Trends Across an Active ATS™ floway (see footnote 13**)**



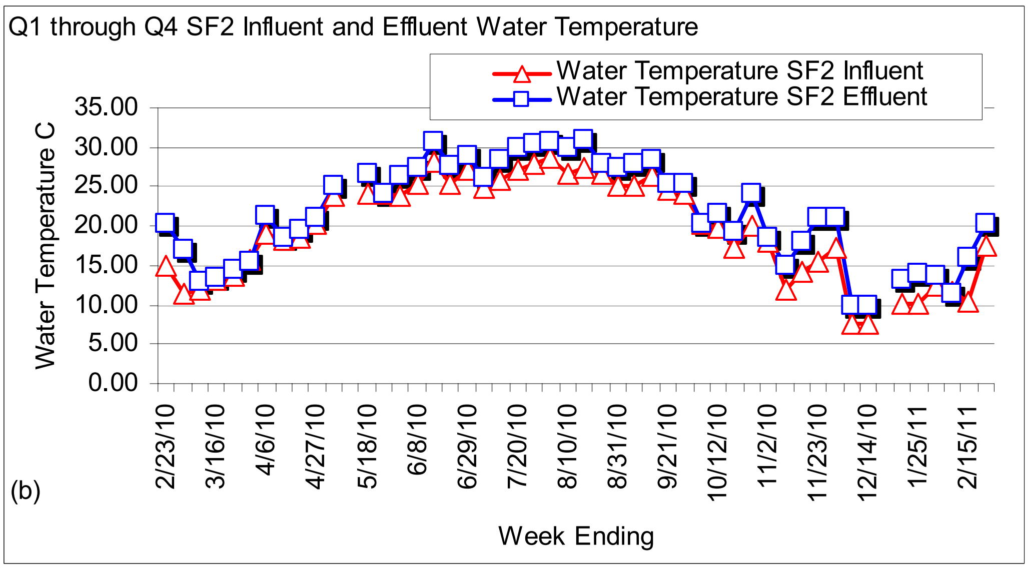


Figure 37: Daytime Water Temperature Trends for Floways SF1 (a) and SF2 (b) during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

<u>Conductivity</u>

The Santa Fe River water is comparatively low in ionic activity, and accordingly is characterized by low conductivity, often less than 100 microS/cm. When flows move across an ATS™ floway, there normally is very little shift in conductivity from influent to effluent. The changes that are noted are typically attributable to temperature changes, with the effluent normally having somewhat higher conductivity levels during the warm daytime period (Figure 38). During both Q1 and Q2 influent and effluent conductivities were very similar, with both floways (SF1 and SF2) showing the same patterns (Table 13 and Figure 39). Conductivities increased slightly during Q3 and Q4, most likely indicative of greater flow percentage from deeper, more mineralized groundwater during the dry season.

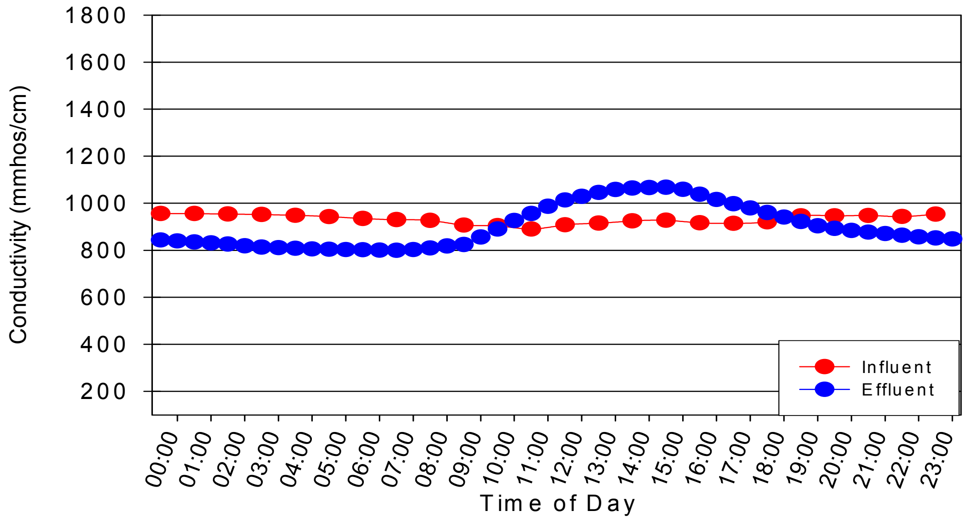
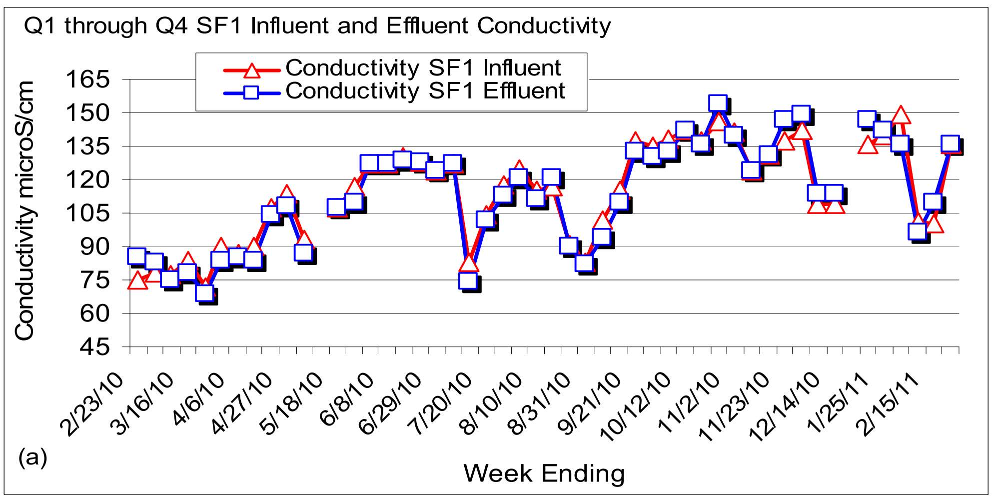


Figure 38: Typical Diurnal Conductivity Trends Across an Active ATS™ floway



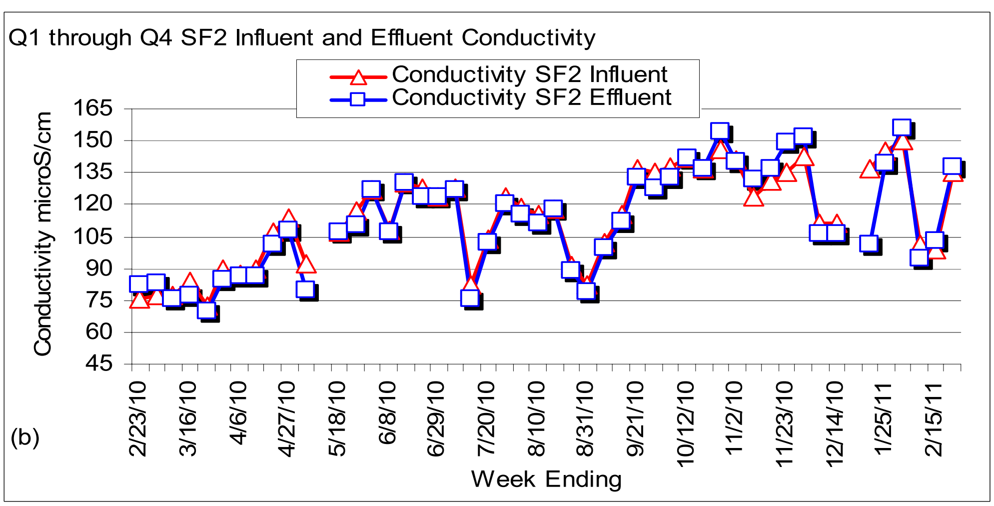


Figure 39: Daytime Conductivity Trends for Floways SF1 (a) and SF2 (b) during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

Calcium, Magnesium and Iron

As noted, the mineral content of the Santa Fe River water near Boston Farm is low when compared to many surface and ground waters in Florida (Table 15). Of particular note are the low calcium concentrations, which are about half of what might be seen in many of Florida's soft water lakes. Both calcium and magnesium increased slightly from Q1 to Q4. The low mineral content is reflected in the algal tissue, with calcium levels being notably low, (although they did increase somewhat during Q2), when compared with tissue from other floways operated by HydroMentia (Table 16). The Everglades system shown in Table 16 was a hard water, high in calcium and magnesium. Lake Lawne was a soft water lake with calcium levels at about 25 mg/L. Egret Marsh has moderate mineral levels. HydroMentia has not in its experience ever observed any productivity issues related to mineral deficiencies, but it is recognized that mineral concentrations and ratios could in certain situations be important factors regarding system productivity and community composition.

Table 15: Influent Calcium, Magnesium and Iron during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

Date	Influent Calcium (mg/L)	Influent Magnesium (mg/L)	Influent Iron (mg/L)
3/16/2010	10.3	3.7	0.576
4/20/2010	10.6	4.2	0.642
5/18/2010	9.7	3.5	0.677
6/8/2010	11.8	4.2	0.716
8/3/2010	12.1	4.1	0.438
8/31/2010	9.8	3.1	0.881
9/28/2010	14.3	5.3	0.604
10/26/2010	15.9	6.6	0.273
1/18/2011	18.6	8.0	0.106

Table 16: Calcium, Magnesium and Iron Tissue Levels during the Q1 through Q4 Santa Fe ATS™ Monitoring Period Compared to Other Florida ATS™ Floways and General Sufficiency Levels for Hydroponic Macrophyte Systems

Element	Unit	Santa Fe ATS™ Pilot (Alachua County, FL) (Q1)	Santa Fe ATS™ Pilot (Alachua County, FL) (Q2)	Santa Fe ATS™ Pilot (Alachua County, FL) (Q3)	Santa Fe ATS™ Pilot (Alachua County, FL) (Q4)	Lake Lawne ATS™ Pilot (Orange County, FL) (May and June 2009)	STA-1W (West Palm Beach County, FL) (March 2009)	Egret Marsh ATS™ Indian River County (Aug, 2010)	S-154 Basin (Okeechobee County, FL) (March 2004)	General Sufficiency Levels for Hydroponic systems[16]
Calcium	% dry weight	0.91	1.82	1.62	0.91	4.40	20.54	9.06	2.06	1.9-2.5
Magnesium	% dry weight	0.30	0.38	0.35	0.23	0.30	0.76	0.43	0.89	0.30-0.50
Iron	mg/kg	10,946	20,254	19,899	12,034	20,687	488	23,187	20,384	50-150

[16] These ranges are provided as a general guide, and do not necessarily represent sufficiency levels applicable to algae.

Suspended Solids

The data for Q1 provided indication that there was a net increase in total suspended solids (TSS) for both floways. The TSS within the influent was comparatively low, averaging 2.14 mg/L, with a standard deviation of 1.35 mg/L and values ranging from 1.16 to 6.00 mg/L. Floway SF1 showed an average effluent TSS of 5.01 mg/L with a standard deviation of 2.43 mg/L and values ranging from 1.16 to 9.20 mg/L. Floway SF2 showed an average effluent TSS of 4.20 mg/L with a standard deviation of 3.05 mg/L and values ranging from 1.16 to 11.60 mg/L. These additional solids were associated with sloughed algae tissue. In a full scale operation the effluent would be screened prior to sampling through a ¼" mesh automatic rake (FlexRake). To emulate the influence of such a rake, the MPU effluent box was fitted with a simple static screen. While this has been effective in some previous MPU application, it was not sufficient in this project to protect the sampling unit from intrusion of sloughed solids. It is noteworthy that an increase in TSS by 2-3 mg/l, could result an additional TP and TN in the effluent of 0.014 to 0.021 mg/L and 0.060 to 0.090 mg/L respectively, so management of effluent TSS is important in terms of overall system efficiency.

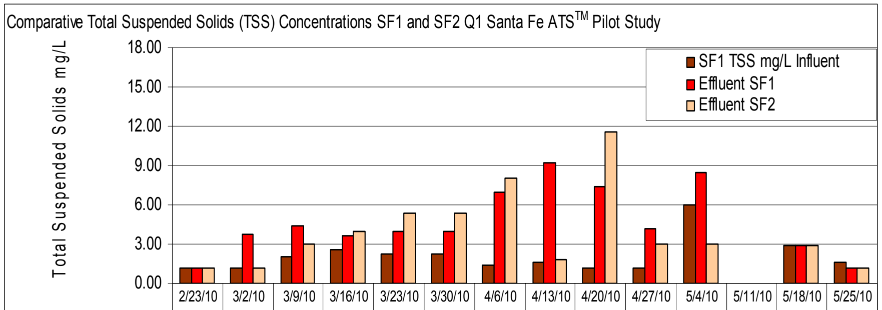
In an effort to resolve the issue of sloughed solids, the conventional static screens were replaced with 500-micon inclined wedge wire screen designed to remove suspended solids from the flow stream. A unit was placed in SF1 on 4/27/10 and in SF2 on 5/11/10.

With installation of a wedge wire screen at the effluent, a reduction of sloughed solids within the effluent was noted. For Q2 the influent TSS averaged 2.23 mg/L, with a standard deviation of 1.63 mg/L and values ranging from 1.40 to 7.50 mg/L. Floway SF1 showed an average effluent TSS of 2.67 mg/L with a standard deviation of 1.98 mg/L and values ranging from 0 to 7.75 mg/L. Floway SF2 showed an average effluent TSS of 2.63 mg/L with a standard deviation of 1.08 mg/L and values ranging from 1.20 to 4.40 mg/L.

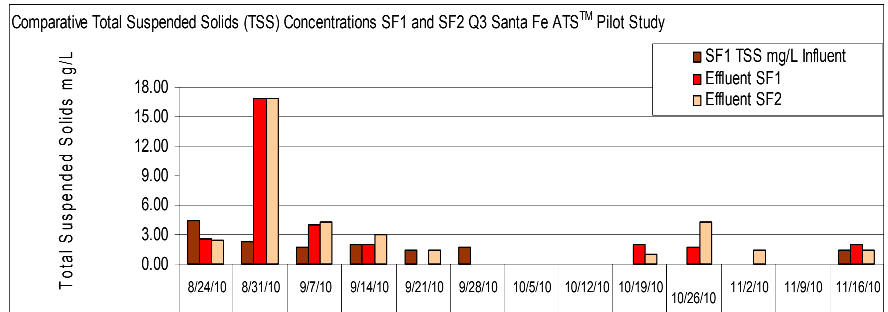
For Q3 the influent TSS averaged 1.74 mg/L, with a standard deviation of 1.34 mg/L and values ranging from 0.00 to 4.40 mg/L. Floway SF1 showed an average effluent TSS of 2.40 mg/L with a standard deviation of 4.52 mg/L and values ranging from 0.00 to 16.80 mg/L. Floway SF2 showed an average effluent TSS of 2.78 mg/L with a standard deviation of 4.47 mg/L and values ranging from 0.00 to 16.80 mg/L. The high effluent TSS associated with both floways of 16.80 mg/L occurred during the week ending 8/31/2101. The Q3 average effluent TSS without this high value was 1.20 mg/l for SF1 and 1.61 mg/L for SF2. Such isolated increases may indicate some type of system upset. In the case of the week ending 8/31/10, the flow was dramatically reduced because of loss of service of one pump. This loss was related to dropping river levels, and a subsequent reduction of flow within the intake (suction) line due to an increased suction head demand.

For Q4 the influent TSS averaged 3.10 mg/L, with a standard deviation of 5.79 mg/L and values ranging from 0.00 to 18.20 mg/L. Floway SF1 showed an average effluent TSS of 2.33 mg/L with a standard deviation of 2.66 mg/L and values ranging from 0.00 to 7.00 mg/L. Floway SF2 showed an average effluent TSS of 2.33 mg/L with a standard deviation of 1.82 mg/L and values ranging from 0.00 to 6.25 mg/L.

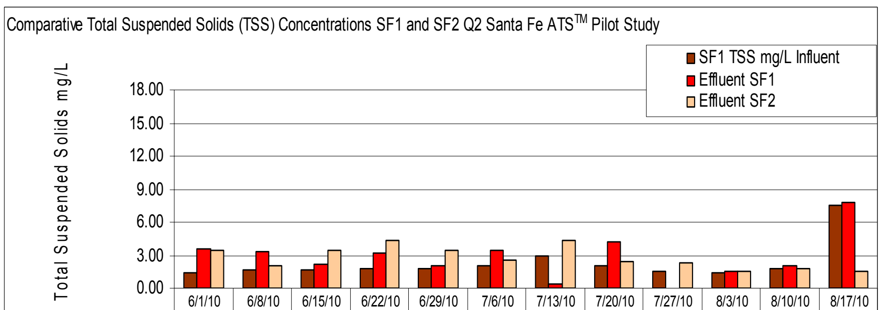
For the Q1 through Q4 monitoring period the influent TSS averaged 2.02 mg/L, with a standard deviation of 2.91 mg/L and values ranging from 0.00 to 18.20 mg/L. Floway SF1 showed an average effluent TSS of 3.11 mg/L with a standard deviation of 3.20 mg/L and values ranging from 0.00 to 16.80 mg/L. Floway SF2 showed an average effluent TSS of 2.89 mg/L with a standard deviation of 2.95 mg/L and values ranging from 0.00 to 16.80 mg/L. Trends related to TSS are seen in Figure 40.Because of the possible influence of suspended solids upon total phosphorus concentration in the effluent, it may be necessary to include more effective unit processes for removing the solids as part of a full scale operation. Such unit processes could include filters such as the Parkson DynaSand filter; self cleaning hydroscreens; self cleaning wedge wire screens; conventional clarifiers; self cleaning rakes; or a combination thereof.



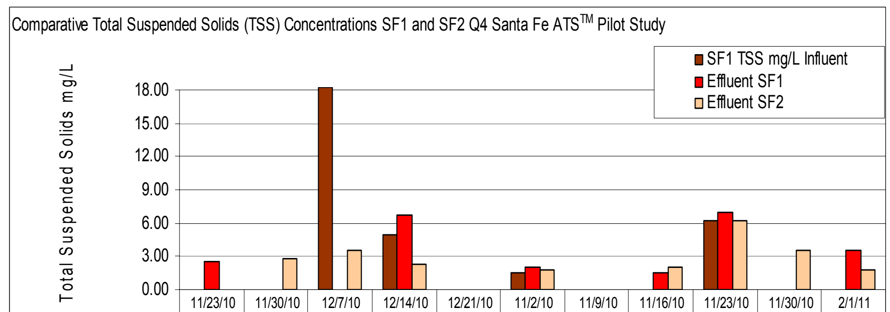
	2/23/10	3/2/10	3/9/10	3/16/10	3/23/10	3/30/10	4/6/10	4/13/10	4/20/10	4/27/10	5/4/10	5/11/10	5/18/10	5/25/10
SF1 TSS mg/L Influent	1.16	1.20	2.00	2.60	2.20	2.20	1.40	1.60	1.20	1.20	6.00	0.00	2.90	1.60
Effluent SF1	1.16	3.80	4.40	3.60	4.00	4.00	7.00	9.20	7.40	4.20	8.50	0.00	2.90	1.16
Effluent SF2	1.16	1.16	3.00	4.00	5.40	5.40	8.00	1.80	11.60	3.00	3.00	0.00	2.90	1.20



	8/24/10	8/31/10	9/7/10	9/14/10	9/21/10	9/28/10	10/5/10	10/12/10	10/19/10	10/26/10	11/2/10	11/9/10	11/16/10
SF1 TSS mg/L Influent	4.40	2.25	1.75	2.00	1.50	1.75	0.00	0.00	0.00	0.00	0.00	0.00	1.50
Effluent SF1	2.60	16.80	4.00	2.00	0.00	0.00	0.00	0.00	2.00	1.75	0.00	0.00	2.00
Effluent SF2	2.40	16.80	4.25	2.95	1.50	0.00	0.00	0.00	1.00	4.25	1.50	0.00	1.50



	6/1/10	6/8/10	6/15/10	6/22/10	6/29/10	7/6/10	7/13/10	7/20/10	7/27/10	8/3/10	8/10/10	8/17/10
SF1 TSS mg/L Influent	1.40	1.64	1.60	1.80	1.80	2.00	3.00	2.00	1.50	1.45	1.75	7.50
Effluent SF1	3.60	3.30	2.20	3.20	2.00	3.40	0.40	4.20	0.00	1.50	2.00	7.75
Effluent SF2	3.40	2.00	3.40	4.40	3.40	2.60	4.40	2.40	2.25	1.50	1.75	1.50



	11/23/10	11/30/10	12/7/10	12/14/10	12/21/10	11/2/10	11/9/10	11/16/10	11/23/10	11/30/10	2/1/11
SF1 TSS mg/L Influent	0.00	0.00	18.20	5.00	0.00	1.50	0.00	0.00	6.25	0.00	0.00
Effluent SF1	2.50	0.00	0.00	6.75	0.00	2.00	0.00	1.50	7.00	0.00	3.50
Effluent SF2	0.00	2.75	3.50	2.25	0.00	1.75	0.00	2.00	6.25	3.50	1.75

Figure 40: Total Suspended Solids (TSS) Trends for Floways SF1 and SF2 during the Q1 through Q4 Monitoring Period - Santa Fe ATS™ Pilot Program

Review of Surger Influence on ATS™ System Performance

Following Q1, a meeting was held with the teams from HydroMentia and the University of Florida. At this time, it was decided to attempt to assess the impacts of surging[17] upon system behavior. Consequently, surging was terminated on Floway SF2 from July 20, 2010 until August 17, 2010. Researchers at the University of Florida elected to re-initiate surge on Floway SF2 on August 17, 2010. A summary of system performance is shown in Tables 17 and 18.

The algal genus distribution varied somewhat between the two floways during this test period, and the tissue from SF1, the surged floway, showed somewhat higher nutrient levels in the tissue. Floway SF1 which retained the surging, showed a higher development of the green algae *Cladophora sp.,* with the *Cyanobacteria, Microcystis sp.* appearing in association with the green algae. The *Cyanobacteria* became more prevalent towards the end of the testing period. Floway SF2 showed more filamentous diatoms, such as *Melosira sp.* and *Fragilaria sp.,* with less *Cladophora sp.* and *Microcystis sp.* In general growth appeared more luxuriant within Floway SF1.

In reviewing the data noted in Tables 17 and 18, it appears that the surging may have been helpful in promoting productivity and nitrogen removal, particularly TKN removal. It also appears that the phosphorus removal may have been better in the floway (SF2) with no surge. When t-tests were applied to the data, the only statistically significant (at 0.95 confidence) data group was the difference between the two floways in concentrations between influent and effluent for total phosphorus. However, with only four data points, it is not reasonable to view any of these trends as conclusive. During Q3 and Q4 SF1 showed higher performance in terms of TKN and TN Areal Removal Rates, and slightly better performance for TP, which may relate to the brief surge termination, although this is certainly not conclusive.

Based upon this brief test, from an observational perspective, the surging did appear to influence turf composition, and non-surging may improve TP reduction slightly, although the surged floway during the following Quarter (Q3) showed better TKN and TP removal rates. It is suggested a longer testing period be conducted before offering a more assertive opinion related to the influence of surging upon overall system dynamics.

[17] Surging is provided by an automatic siphon device. The intermittent release of water and the following no flow period is intended to emulate oscillatory waves as might be seen in nature. This pulsing of flows has been suggested as stimulative to algal production and viability.

Table 17: Comparative Performance of SF1 and SF2 during Surge/No Surge Test Period 7/27/10 to 8/17/10.

	Dry Harvest lb		Tissue P Content % dw*		Tissue N Content % dw*		Productivity g/m^2-day		Water Quality Based TP removed g		Water Quality Based TN removed g		TKN removed g		NOx-N removed g	
Week Ending	SF1	SF2	SF1	SF2	SF1	SF2	SF1	SF2	SF1	SF2	SF1	SF2	SF1	SF2	SF1	SF2
7/27/10			0.76%	0.66%	2.82%	2.20%			21	27	193	156	89	52	104	104
8/3/10	14.06	11.04	0.76%	0.66%	2.82%	2.20%	9.00	7.32	20	24	22	59	-81	-44	104	104
8/10/10			0.76%	0.66%	2.82%	2.20%			24	29	262	178	148	62	115	115
8/17/10	7.43	8.69	0.76%	0.66%	2.82%	2.20%	4.68	5.89	17	22	141	-19	64	-104	77	85
Total	21.49	19.73					7.50	6.88	61	75	425	218	130	-86	295	304

* August Data used for Testing Period

Table 18: Comparative Nutrient Concentrations of SF1 and SF2 during Surge/No Surge Test Period 7/27/10 to 8/17/10.

	Influent TP mg/L	Effluent TP mg/L		Influent OP mg/L	Effluent OP mg/L		Influent TN mg/L	TN mg/L		Influent TKN mg/L	TKN mg/L		Influent Nox-N mg/L	Nox-N mg/L	
Week Ending	Common	SF1	SF2	Common	SF1	SF2	Common	SF1	SF2	Common	SF1	SF2	Common	SF1	SF2
7/27/10	0.281	0.253	0.221	0.221	0.232	0.245	1.27	1.01	1.06	1.08	0.96	1.01	0.19	0.05	0.05
8/3/10	0.256	0.229	0.213	0.213	0.21	0.224	0.90	0.87	0.82	0.71	0.82	0.77	0.19	0.05	0.05
8/10/10	0.263	0.23	0.202	0.202	0.205	0.222	1.22	0.86	0.98	0.98	0.78	0.90	0.24	0.08	0.08
8/17/10	0.288	0.266	0.246	0.246	0.241	0.259	1.01	0.82	1.03	0.86	0.77	0.99	0.15	0.05	0.04
Mean	**0.272**	**0.245**	**0.221**	**0.221**	**0.222**	**0.238**	**1.10**	**0.89**	**0.97**	**0.91**	**0.83**	**0.92**	**0.19**	**0.06**	**0.06**

Floway Comparative Performance Summary

During the monitoring period Q1 through Q4, both floways provided good performance in terms of areal removal rates for both nitrogen and phosphorus, with floway SF1 showing somewhat better TKN removal rates, which is suggestive that it developed communities within the algal turf which could access organic nitrogen more effectively. Both floways provided mass NOx-N removal of over 55%. Productivity through the monitoring period was similar for both floways, 4.57 g/m^2-day for SF1 and 5.75 g/m^2-day for SF2. The comparative performances are noted in Table 19.

Table 19: Comparative Performances of SF1 and SF2 during Q1 through Q4

Floway	TN Areal Removal Rate g/m^2-yr (% Removal)	TKN Areal Removal Rate g/m^2-yr (% Removal)	NOx Areal Removal Rate g/m^2-yr (% Removal)	TP Areal Removal Rate g/m^2-yr (% Removal)	OP Areal Removal Rate g/m^2-yr (% Removal)	Net Community Production g/m^2-day
SF1	157.57 (18.75%)	103.29 (13.90%)	54.28 (55.89%)	17.79 (9.57%)	12.50 (8.30%)	4.57
SF2	103.60 (12.34%)	49.38 (6.65%)	54.22 (55.77%)	17.51 (8.83%)	8.61 (5.57%)	5.04

C:N:P Ratios

Regarding the relative importance of carbon and nitrogen, it is helpful to review the atomic ratios of C:N:P (Table 20). The typical ratio considered optimal for primary production is 160:16:1, although this certainly varies somewhat, depending upon site conditions and species composition. This ratio is based upon elemental molar concentrations (i.e. micromoles/L), whereby using the 1 micromole of carbon as 12 mg/L, nitrogen as 14 mg/L and phosphorus as 31 mg/L.

Table 20: Comparative C:N:P atomic ratios for influent and algal turf tissue Q1 through Q4

Quarter	C:N:P (Water)	C:N:P (Tissue)
Q1	88:11:1	64:8:1
Q2	62:10:1	86:11:1
Q3	85:9:1	77:10:1
Q4	165:7:1	48:7:1
Q1 through Q4	99:9:1	69:9:1

The water and tissue ratios are similar, as expected. The ratios shown imply that there is a noticeable paucity of available carbon (except for Q4), and that nitrogen is also somewhat limited. Recognizing that much of the nitrogen in the water may not be available, the issue of nitrogen limitation becomes more accentuated. The downstream waters within the Suwannee River generally show C:N:P ratios closer to the ideal 160:16:1, and accordingly would be expected to support a more active and productive algal turf community.

SECTION 4: DATA ANALYSIS AND MODELING REVIEW

Statistical Review of Nutrient Data

Because the level of reliability of the laboratory analysis is about 20% Relative Percent Difference (RPD), the influent and effluent data needs to be evaluated to determine if the differences noted are statistically indicative of removal. To do this a one tailed t-Test was completed on the influent and effluent concentrations for TP, with the null hypothesis being that the influent concentrations are less than or equal to the effluent concentration. This is a one-tailed hypothesis, with the critical value at 95% confidence value at approximately -1.66 to -1.67. The results are noted in Table 21. Several things are particularly noteworthy regarding this analysis.

- There is 95% confidence that the effluent TP concentration is less than the influent TP concentration for both floways, and that there is total phosphorus removal through the system.

- The confidence that the effluent ortho phosphorus is less than the influent ortho phosphorus is below 95% confidence for both floways. This suggests that there is likely a balance between the generation of ortho phosphorus from organic phosphorus via enzymatic hydrolysis and the uptake of ortho phosphorus by the algal turf. This input and output flux of ortho phosphorus is why it is not a good indicator of total phosphorus removal

- There is >95% confidence that the effluent TN concentration is less than the influent TN concentration for both floways, and that there is total nitrogen removal through the system.

- There is >95% confidence that the effluent TKN concentration is less than the influent TKN concentration for floway SF1, but <95% confidence that the effluent TKN concentration is less than the influent TKN concentration for floway SF2. This illustrates the issue which has been noted in the text that there is a disparity in net TKN removal between the two floways. The apparent lack of consistent removal of TKN within SF2 may indicate an absence of enzymatic hydrolysis, or a failure of the algal turf to access what available ammonia-N is associated with the SF2 TKN.

- There is >95% confidence that the effluent NOx-N concentration is less than the influent NOx-N concentration for both floways, and that there is NOX-N removal through the system.

- The high percentage reduction of NOx-N is likely due to direct turf uptake, although denitrification, while unlikely because of the highly oxidized environment and low organic content of the flows, could be a contributor. Because there is a net removal of NOx-N, it is suspected that very little input to the NOx-N compartment is from nitrification.

Table 21: One tailed t-Test analysis of influent and effluent nutrient data

Null Hypothesis	**Mean influent Concentration ≤ Mean effluent Concentration**			
Parameter/ Floway	**Degrees of Freedom**	**Critical value at 0.05 significance one-tailed**	**t- value**	**Comment**
Total P/SF1	93	-1.66	-1.92	Null Hypothesis rejected
Total P/SF2	93	-1.66	-1.68	Null Hypothesis rejected
OP/SF1	94	-1.66	-1.45	Null Hypothesis accepted
OP/SF2	94	-1.66	-0.99	Null Hypothesis accepted
Total N/SF1	94	-1.66	-3.36	Null Hypothesis rejected
Total N/SF2	87	-1.67	-2.38	Null Hypothesis rejected
TKN/SF1	95	-1.66	-2.36	Null Hypothesis rejected
TKN/SF2	88	-1.67	-1.25	Null Hypothesis accepted
NOx-N/SF1	90	-1.66	-5.35	Null Hypothesis rejected
NOx-N/SF2	81	-1.67	-5.72	Null Hypothesis rejected

Modeling Considerations—ATSDEM Adjustment

The ATSDEM model was developed by HydroMentia to establish a means of developing initial assessments of system performance, and for sizing facilities during preliminary engineering efforts. The model can also be used during operations for establishing harvesting regimens and adjustments to hydraulic loading. The model is based upon the Monod[18] relationship and first order dynamics applied to a community rather than an enzyme or individual species, such as is done with other commercial biological process (e.g. activated sludge). The Monod relationship is expressed as:

$$\mu = \mu_{max}S/(K_s+S)$$

Where μ_{max} is the maximum potential growth rate and K_s is the half-rate constant for growth limited by **S**, or the value of **S** when $\mu = ½ \mu_{max}$.

For applications within most freshwater systems, phosphorus along with hydraulic loading and water temperature have been used as key parameters (**S**) for estimating specific growth rate. However, there is indication, as noted in the text, that nitrogen and possibly carbon, rather than phosphorus, is more influential in limiting production within the targeted stretch of the Santa Fe River. Therefore some adjustments of the Monod relationship need to be considered.

A review of the model development is included as Appendix A. Critical model inputs include:

- **a.** Water Temperature
- **b.** Linear hydraulic loading rate
- **c.** Relationship between tissue nutrient content and nutrient water levels
- **d.** Total Phosphorus concentration
- **e.** Total Nitrogen Concentration
- **f.** Initial crop density

[18] Monod J. (1942) *Recherches sur la Croissance ds Cultures Bacteriennes,* Herman et Cie, Paris

- **g.** Average crop density between harvests
- **h.** Harvest frequency
- **i.** Alkalinity
- **j.** pH
- **k.** Maximum Net Community Specific Growth rate (1/hr)
- **l.** Half Rate Concentration of Limiting Nutrient
- **m.** Half Rate Concentration of LHLR
- **n.** V'ant Hoff-Arrhenius Constant (for adjusting growth rate to temperature)

During the course of the pilot term, specific growth rate was calculated with each harvest. This rate expresses in the case of the ATS™ a net community growth rate, and is used to project net productivity through the first order equation:

$$Z_t = Z_0 e^{\mu t}$$

Where **Z** is the dry biomass weight, **t** is the time interval, and μ is the net community specific growth rate (1/time)

Specific growth rates can be adjusted for temperature by using the V'ant Hoff-Arrhenius equation:

$$\mu_2 / \mu_1 = \Theta^{(T_{opt}-T_1)} \quad \text{or} \quad \mu_1 = \mu_2 / \Theta^{(T_2-T_1)} \quad 125$$

Where μ_2 is the growth rate for given **S** at an optimal growing temperature °C, T_2, and μ_1 is the growth rate for the same given **S** at some temperature °C, T_1, when $T_1 < T_2$, and Θ is an empirical constant ranging from 1.03 to 1.10.

As noted, the harvested calculations during the project term did not balance very well with the water quality calculations, being considerably lower in term of nutrient mass removals. Therefore the specific growth values developed from the harvest data was erratic, and did not correlate well with any of the nutrient levels or with removal rates. Consequently, a better indicator of system performance and production in this case was actual nutrient removal rates calculated from the more reliable water quality and flow data. Because total phosphorus is much more stable than nitrogen in terms of the extent and likelihood of external gains and losses, the total phosphorus areal removal rates (TP-ARR) is used as the performance indicator, and as a tool for estimating net productivity and growth rates.

When TP-ARR is used as the dependent variable against total phosphorus, total nitrogen, ortho phosphorus, TKN and NOx-N concentrations, the regression analysis shows reasonable correlations, considering the influence of other factors such as shut-downs and other disruptions, with total nitrogen having the highest regression coefficient (r^2), as noted in Table 22

From the total phosphorus removals it is reasonable to estimate net specific community growth rates for each harvest period:

$$P_{net} = (P_{mw} / p) / A t_h$$

Where P_{net}= net productivity in dry-g/m^2-yr per harvest period t_h in days
P_{mw} = mass in g of phosphorus removed based upon water quality calculations over t_h
p = tissue phosphorus content as fraction of dry harvest
A = Floway area in m^2

Table 22: Summary of regression analysis TP-ARR Vs Influent Nutrient Concentrations

Dependent Variabe	Independent Variable	r^2
TP-ARR	TP Influent Concentrations	0.51
TP-ARR	OP Influent Concentration	0.32
TP-ARR	TN Influent Concentration	0.57
TP-ARR	TKN Influent Concentration	0.55
TP-ARR	NOx-N Influent Concentration	0.15

It is also possible to estimate the net community specific growth rate μ as 1/hr for each harvest by:

$$\mu = \{\ln[(P_{mw} / p)/A\mathbf{Z_0}]\}/24\mathbf{t_h}$$

If the initial standing crop $\mathbf{Z_0}$ is set at 10 dry-g/m^2, which has been found to be a reasonable estimate for the residual crop left after harvest, then:

$$\mu = \{\ln[0.1(P_{mw} / p)/A]\}/24\mathbf{t_h}$$

When this approach is applied to the data for SF1, the productivity and growth rate estimates are as shown in Table 23. Note that the average productivity of 7.63 g/m^2-day and the net community specific growth rate of 0.0063/hr are somewhat higher than those calculated from the harvest data - 4.57 g/m^2-day and 0.0060/hr.

There are several methods which have been developed to calculate the Monod parameters of maximum specific growth rate (μ_{max}) and half rate concentration $\mathbf{K_s}$. The one which was used in developing the ATSDEM model is the Hanes[19] method as described by Brezonik[20]. The Hanes equation as developed from the Monod relationship is:

$$[S]/\mu = K_s/(\mu_{max}) + (1/(\mu_{max}) [S]$$

When plotted, the slope is $\mathbf{1/\mu_{max}}$, and y-intercept is $\mathbf{K_s/\mu_{max}}$ **.** To complete the Hanes plot for **S** as total nitrogen it is first necessary to bring the net community specific growth rates to a common temperature using the previously noted V'ant Hoff-Arrhenius equation. This conversion is shown in Table 24, along with average water temperatures and total nitrogen concentrations for each harvest period. The Hanes Plot was completed for Quarters 2 through 4, with Q1 data considered start-up and somewhat anomalous. This plot as shown in Figure 40 reveals a μ_{max} of 0.0289 and $\mathbf{K_s}$ of 1.00 mg/L as TN. The correlation coefficient (r^2) is 0.36. This exercise needs to be recognized as an approximation, to be used in developing projections for full scale results. Because this is an application on the ecosystem level, rather than the enzymatic or species level, and is not conducted under laboratory conditions, there is substantial opportunity for error. But, like other full scale biological processes, such approximations serve in setting the general range for system behavior.

[19] Hanes, C.S. (1942) *Biochem. J.* , 26, 1406
[20] Brezonik, P.L. (1993) Chemical Kinetics and Process Dynamics in Aquatic Systems Lewis Publishers, Boca Raton, Fl pp 421-427 ISBN 0-87371-431-8

Table 23: Summary of productivity and net community specific growth rates from total phosphorus removal data SF1

SF1

Date of Harvest	Phosphorus Removed per water quality calculations (P_{mw}) g	Tissue P (p) % dry weight	Harvest period (t_h) days	Floway Area (A) m^2	Estimated Net Productivity (P_{net}) g/m^2-day	Estimated Net Community Specific Growth Rate (μ) 1/hr
3/16/10	4.20	0.65%	7	46.47	1.99	0.00196
3/30/10	8.89	0.65%	14	46.47	2.10	0.00321
4/6/10	26.64	0.65%	7	46.47	12.60	0.01296
4/13/10	6.31	0.65%	7	46.47	2.98	0.00439
4/20/10	24.16	0.65%	7	46.47	11.43	0.01238
4/27/10	23.69	0.65%	7	46.47	11.20	0.01226
5/4/10	30.48	0.80%	7	46.47	11.71	0.01252
5/25/10	120.96	0.80%	21	46.47	15.49	0.00691
6/29/10	192.07	0.84%	35	46.47	14.06	0.00464
7/20/10	85.03	0.69%	21	46.47	12.63	0.00650
8/3/10	40.76	0.76%	14	46.47	8.24	0.00728
8/17/10	40.60	0.76%	14	46.47	8.21	0.00727
9/14/10	23.38	0.72%	7	46.47	9.98	0.01157
9/28/10	26.87	0.72%	14	46.47	5.74	0.00620
10/12/10	12.87	0.60%	14	46.47	3.30	0.00455
11/2/10	30.55	0.85%	21	46.47	3.68	0.00406
11/30/10	24.35	0.85%	28	46.47	2.20	0.00271
2/8/11	108.58	0.81%	28	46.47	10.30	0.00500

Table 24: Summary of adjusted growth rates, water temperatures, average standing crops and total nitrogen SF1

T_2= 29
Θ= 1.03

Date of Harvest	Estimated Net Community Specific Growth Rate (m) 1/hr	Average Water T °C	Temperature adjusted Net Community Specific Growth Rate (μ) 1/hr	Average TN [S] mg/l	Average Standing Crop g/m^2	[S]/μ
3/16/10	0.00196	13.73	0.0029	1.01	12.10	353
3/30/10	0.00299	14.51	0.0043	0.89	18.70	207
4/6/10	0.01211	17.85	0.0159	0.97	10.50	61
4/13/10	0.00353	19.36	0.0045	1.03	41.80	229
4/20/10	0.01152	18.26	0.0150	1.06	15.60	71
4/27/10	0.01141	17.26	0.0152	1.19	38.90	78
5/4/10	0.01252	22.59	0.0147	1.21	38.30	82
5/25/10	0.00691	24.76	0.0077	1.52	98.28	199
6/29/10	0.00464	26.54	0.0049	1.59	130.75	322
7/20/10	0.00650	27.31	0.0068	1.16	84.09	171
8/3/10	0.00728	29.37	0.0072	1.13	46.97	157
8/17/10	0.00727	27.28	0.0076	1.04	46.84	138
9/14/10	0.01157	28.80	0.0116	1.20	35.28	103
9/28/10	0.00620	25.74	0.0067	1.32	36.33	196
10/12/10	0.00455	21.92	0.0054	1.00	24.96	185
11/2/10	0.00406	19.71	0.0051	0.89	34.55	175
11/30/10	0.00271	15.12	0.0038	0.71	29.33	185
2/8/11	0.00500	12.34	0.0075	0.77	87.90	102

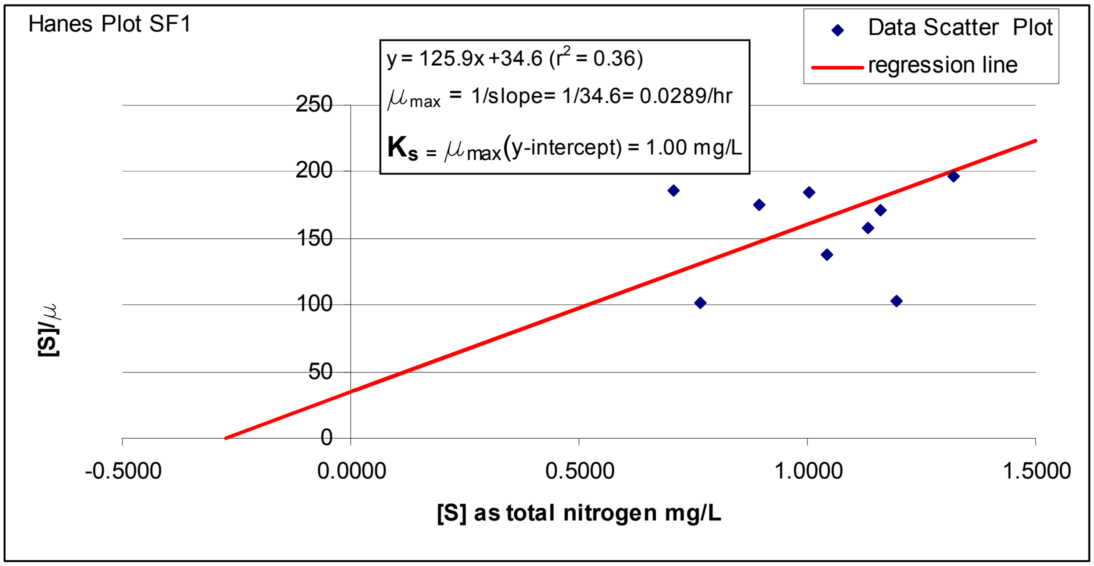


Figure 40: Hanes Plot Q2-Q4 water quality calculated growth rates with total nitrogen SF1

Using the Hanes plot data and the field data, reasonable conditions for an initial ATSDEM modeling can be established as shown in Table 25. A summary of the ATSDEM runs for each quarter is shown in Table 26. As noted the model tracks the process rather closely. Refinements to the model would be facilitated by continuation of the pilot work at higher alkalinities and NOx-N levels, with closer monitoring of ammonia-N and alkalinity concentrations.

Table 25: Control Parameters for ATSDEM Run SF1

Parameter	Value
Maximum Specific Growth Rate 1/hr	0.0298
Optimal Average Crop Density dry g/sm	circa 55.6
V'ant Hoff-Arrhenius Constant	1.03
Optimal Growth Temperature °C	29
Half Rate Concentration TN mg/l	1.00
Half Rate LHLR gpm/lf	9.3
Tissue Nitrogen % dry weight to Nitrogen Concentration	2.86
Tissue Phosphorus % dry weight to Phosphorus Concentration	0.73

Table 26: ATSDEM Run SF1 Q1-Q4

Quarter	Effluent Phosphorus µg/L		Effluent Nitrogen mg/L	
	ATSDEM projection	Actual	ATSDEM projection	Actual
Q1	189	189	1.01	0.99
Q2	254	255	1.14	0.95
Q3	226	240	0.95	0.85
Q4	230	223	0.67	0.68

SECTION 5: FINAL CONCLUSIONS AND RECOMMENDATIONS

- Based on the Santa Fe ATS™ Pilot test results, the Algal Turf Scrubber® nitrogen removal performance is consistent with projections provided in the 2006 Preliminary Engineering Assessment.

- The Algal Turf Scrubber® can effectively reduce NOx-N and TN loads in the Suwannee River watershed, thereby providing a regional option to meet TMDL nitrogen load reduction goals.

- The ATS™ system primarily reduces biologically available nitrogen such as NOx-N, thereby maximizing treatment benefits for the Suwannee River.

- Testing on the relative low NOx-N and low alkalinity waters associated with the Santa Fe River near Boston Farm confirms that the Algal Turf Scrubber® technology will achieve high rates of NOx-N removal even as concentrations in the Suwannee River are reduced towards the long-tem NOx-N target of 0.35 mg/l.

- The ATS™ system increased dissolved oxygen levels 58% to 61%. As a secondary benefit of ATS™ nitrogen treatment, increased oxygen levels associated with ATS™ discharges would benefit receiving waters in the Suwannee and Santa Fe River watersheds that are currently impaired due to low oxygen levels.

- It is recommended that the Santa Fe ATS™ pilot investigation be extended, and that supplementation with bicarbonate to increase alkalinity and NOx-N be included in an effort to emulate downstream conditions within the Middle and Lower Suwannee River system to provide for an optimized ATS™ design for Suwannee River water quality, and that more extensive monitoring of alkalinity and ammonia nitrogen be conducted.

- It is recommended that one Santa Fe ATS™ floway be operated with Santa Fe River as source water, with the second flow receiving flow supplemented with bicarbonate and NOx-N as described above.

- It is recommended that biomass recovered from the Santa FE ATS™ pilot be evaluated by USDA-ARS researchers in regard to its potential product value within the Florida agricultural community. USDA-ARS researchers recently entered a 5-year research program to investigate the Algal Turf Scrubber® technology and algal products produced from the system.

APPENDIX A: SUMMARY OF ATSDEM DEVELOPMENT

Development of an ATS™ Design Model (ATSDEM)

Technical Rationale and Parameter Determination

Modeling of complex, expansive biological processes requires recognition that system behavior is a composite of a number of physical, chemical and biological reactions, and that each has the capability of exerting influence over the other. Within most biological treatment systems, the dominant reactions revolve around enzymatic conversion. These enzymatic reactions will influence both tissue creation and tissue reduction. The more expansive the biological system, the more difficult it becomes to identify and project the dynamics of specific reactions. For example, Walker[i], in modeling treatment wetlands, known as Stormwater Treatment Areas or STA, utilized the resultant, documented removal of phosphorus to establish a general first order equation in which removal is projected, but the mechanisms involved are not individually assessed. This model, Dynamic Model for STA, or DMSTA, while quite reliable over a set period of time, projects only the rate at which phosphorus is accumulated through sediment accretion. Admittedly, it does not include efforts to model or optimize plant productivity, as noted by Walker[21] –"*The model makes no attempt to represent specific mechanisms, only their net consequences, as reflected by long-term average phosphorus budget of a given wetland segment.*"

The principle weakness of the DMSTA approach is that it presumes, and requires storage (peat accumulation), or **$dA/dt > 0$,** with **A** the accreted peat, and **t** is time, while assuming that there is no change in the rate factor, **K_e ,** also know as the effective velocity, or **dK_e /dt = 0.** This relationship is incongruous with the present understanding of ecological succession, as it assumes no relationship between the collection of complex ecological processes and the accumulated stores within the ecosystem. This presumption does not eliminate the inevitability that ultimately there will be a changed ecostructure in which the mechanisms and rates of phosphorus management will change. The need recently to remove accumulated peat within an STA near the City of Orlando[ii] has validated this suspected vulnerability.

Within more compact intensive processes, such as activated sludge and fermentation chambers, as well as MAPS programs, greater management effort is extended towards a specific product, and typically this product is targeted specifically within the modeling efforts. For example, with activated sludge, design and operation relies upon the rate of production of the diverse population of heterotrophic and chemoautotrophic microorganisms, which collectively generate the desired oxidation and consumption of organic debris. These processes are typically compatible with the principles of ecological succession, as the accumulated biomass is removed at frequent intervals, therefore, **$dA/dt = 0$.** This removal stabilizes the system's dynamic, and permits long-term reliability.

MAPS, which include ATS™, are such stabilized systems that rely upon photoautrophic (green plants and certain bacteria) production, and the subsequent removal (harvesting) of accumulated production to preserve relative predictable and reliable performance. Managed photoautotrophic production of course is the basis of much of established agriculture, and has been practiced for several thousands of years—therefore it is not a new concept, and it is understandable that certain aspects of ATS™ resemble conventional farming. The difference between an ATS™ and traditional farming is oriented more around purpose than technique, although to some extent purpose directs technique. With ATS™ and other MAPS it is the intent not to maximize production for the sole purpose of food or fiber cash product generation, but rather maximizing production for the principal purpose of removal of pollutant nutrients. With an ATS™, the resultant crop value is secondary—the larger and more valuable product is enhanced water quality. In other words, algae is not grown because it fixes carbon and thereby generates a valuable product, but because in its growth, supported by the fixation of carbon, it incorporates phosphorus and nitrogen in its tissue, and thereby provides an efficient mechanism for water treatment.

As with many biological water treatment processes, the dynamics associated with the ATS™ can be described as a first-order reaction, where the rate of reaction is proportional to the concentration of the substrate. This can be expressed through Equations 1 through 3.

$$dS/dt = -kS \quad \text{Equation 1}$$

or

$$dS/S = -kdt \quad \text{Equation 2}$$

Integrated between **t = 0** to **t = i** or

$$\ln(S_i/S_0) = -kt \text{ or } S_i = S_0e^{-kt} \quad \text{Equation 3}$$

Where **S** is the nutrient concentration, **t** is time, and **k** is the rate constant

This general expression was initially applied to enzymatic reactions as described by Michaelis-Menten[19]. While the value **"k"** within the laboratory was in these vanguard studies applied to a specific substrate and a specific enzyme, the **"k"** value, as noted previously, has come to be identified within more complex biological treatment processes with the cumulative effect of a broad and fluctuating collection of reactions and organisms. While repetitive experimentation in such cases can strengthen confidence in establishing values for **"k"** on a short-term basis, it cannot, as noted previously, determine the rate of change in **"k"** as environmental conditions change within a system, such as a treatment wetland, which is not managed through tissue removal —i.e. as accretion begins to change to chemical and physical complexion of the process.

Within sustainable biological processes, in which biomass removal allows long-term stabilization of the chemical and physical environment, it is possible to orient the first-order reaction around the principal mechanism involved in nutrient removal—that being actual biomass productivity. In some cases, modeling of this productivity can target a dominant species, such as with the WHS™ technology. However, in most cases, the application of growth models is applied to a set community of involved organisms, such as with activated sludge, fixed film technology, fermentation and ATS™.

Managing a collection of organisms in this manner presents the design challenge of projecting performance of a functioning ecosystem and, in operations, manipulating parameters, to the extent practical, (e.g. hydraulic loading rate, chemical supplementation) such that the most efficient ecostructure in terms of removal of the targeted pollutant, is sustained, and thus provided a selective advantage.

When a biological unit process is oriented around sustainable community production, the first order kinetics are generally applied through the Monod[20] relationship.

$$Z_t = Z_0e^{\mu t} \quad \text{Equation 4}$$

Where **Z** is the biomass weight and μ is the specific growth rate (1/time) when:

$$\mu = \mu_{max}S/(K_s+S) \quad \text{Equation 5}$$

Where μ_{max} is the maximum potential growth rate and K_s is the half-saturation constant for growth limited by **S**, or the concentration of **S** when $\mu = ½\, \mu_{max}$.

Considering the flow dynamic of the ATS™, the system may be viewed as a plug flow system. Recognizing that the average biomass at any one time on the ATS™ is assumed stable (Z_{ave}), and relatively constant when harvesting is done frequently, and the reduction rate at steady state of **S** is also a function of the concentration of **S** within the tissue or S_t, then S_{y1} at a sufficiently small increment ***"y"*** down the ATS™ may be expressed as:

$$S_{y1} = S_{y0} - \{[S_t\{Z_{ave}e^{[\mu][(y_1-y_0)/v]} - Z_{ave}\}]/[q(y_1-y_0)/v]\} \quad \text{Equation 6}$$

Where "**v**" is the flow velocity down the ATS™ at unit flow rate "**q**".

The conditions required for Equation 6 are that the temperature is optimal for growth, that solar intensity is relatively constant, that the process is irreversible, and that there is no inhibitory effects related to **S** within the ranges contemplated, and that the difference between $\mathbf{S}_{y1}$ and $\mathbf{S}_{y0}$ is sufficiently small down **"y"**, as to not influence μ**.** If temperature variations are expected, their impacts need to be considered using the classical V'ant Hoff-Arrhenius[iii] equation (Equation 7), which may be incorporated into the relationship as noted in Equations 8.

$$\mu_{opt}/\mu_1 = \Theta^{(Topt-T1)} \text{ or } \mu_1 = \mu_{opt}/\Theta^{(Topt-T1)} \quad \textbf{Equation 7}$$

Where μ_{opt} is the growth rate for given **S** at the optimal growing temperature °C, $\mathbf{T}_{opt}$, and μ_1 is the growth rate for the same given **S** at some temperature °C, $\mathbf{T}_1$, when $\mathbf{T}_1 < \mathbf{T}_{opt}$, and Θ is an empirical constant ranging from 1.03 to 1.10.

$$S_{y1} = S_{y0} - \{[S_t\{Z_{ave}e^{[\mu(y1-y0)/v][1/\Theta^{(Topt-T1)}]} - Z_{ave}\}]/[q(y_1-y_0)/v]\} \quad \textbf{Equation 8}$$

In more northern applications, adjustments might need to be made for light intensity as well. While there are seasonal fluctuations in Florida for both solar intensity and photoperiod, the impacts are assumed to be minimal when compared to temperature influences, and can be incorporated into the empirical determination of Θ.

Finally, if the right side of Equation 5 is included for μ, then the relationship for concentration of **S**, at the end of segment $\mathbf{y_1}$ becomes Equation 9.

$$S_{y1} = S_{y0} - \{[S_t\{Z_{ave}e^{[\mu_{max}S_{y0}/(Ks+S_{y0})][(y_1-y_0)/v][1/\Theta^{(Topt-T1)}]} - Z_{ave}\}]/[q(y_1-y_0)/v]\} \quad \textbf{Equation 9}$$

Estimation of μ_{max} and $\mathbf{K_s}$ can be done by manipulation of the Monod[20] relationship, noted as Equation 5 to yield linear equations to which field data can be applied and plotted, as discussed by Brezonik[iv]. Several techniques are discussed, including Lineweaver-Burke[v], Hanes[vi] and Eadie-Hofstee[vii]. It is suggested that of the three methods, the Hanes[25] method, which involves the plot of substrate concentrations **S**, as the independent variable, and the quotient of substrate concentration and growth rate, **[S]**$/\mu$, as the dependent variable is the preferred of the three. In such a plot, μ_{max} is represented as the inverse of the slope of the linear equation:

$$[S]/\mu = (K_s/\mu_{max}) + (1/\mu_{max})[S] \quad \textbf{Equation 10}$$

Accordingly, K_s is the negative of the x-intercept, or $K_s = -[S]$, when $[S]/\mu = 0$.

Plotting the single flow data set using the Hanes method is helpful at providing some indication of expected general range of μ_{max} and $\mathbf{K_s}$. The fact that data collection, particularly as related to growth, as noted earlier, is inherently vulnerable to error, and that there are undoubtedly other factors involved in determining production rate that must be considered when deciding how to apply a developed model, and in determining the extent of contingencies included in establishing sizing and operational strategy, non-linear regression analysis, a technique beyond the scope of this review, may result in a set of parameters that provide closer projections.

The data set used in establishing the Hanes plot as shown in Table 4-1, were created from field data incorporated with the following approach:

1. Data was used for that period identified as the adjusted POR, as inclusion of results impacted by the hurricane events, and the associated power outages represent unusual perturbations that would likely influence system performance. This POR was from May 17, 2004 to August 23, and

October 23 to December 6, 2004.
2. Water loss was considered negligible down the ATS™.
3. Crop production was calculated as the mass of total phosphorus removed over the monitoring period divided by the tissue phosphorus content as % dry weight, with the tissue phosphorus content calculated using the equation note in Figure 3-7.
4. Growth rate is calculated by $\ln(Z_t/Z_0)/t = \mu$ with Z_0, the initial algal biomass assumed to be 10 g/m^2 on a dry weight basis, adjusted to optimal growing temperature. This value is based upon a reasonable harvest of 90-95% of standing crop.
5. Optimal growing temperature (water) is set at 30^o C, with $\Theta = 1.10$.
6. Substrate concentration is set as the mean between influent and effluent concentrations.
7. Available carbon concentration is calculated using the method described in Section 3-4.

Scattergrams of the total phosphorus, total nitrogen, available carbon, and linear hydraulic loading rate with calculated growth rate are noted in Figures 4-9 to 4-12. The patterns as seen provide indication that phosphorus influences upon growth rate are more dramatic at lower concentrations, with a “plateau” noted at high concentration indicating rather low values of K_s. Phosphorus appears to be more influential than nitrogen or available carbon. The LHLR however, as noted previously, appears to be quite influential. This may be related to the greater available mass of nutrients per unit time, or to the influences of increased flow velocity, as discussed in a later segment of this section.

Based upon literature review and field observations, it is possible that algae productivity and nutrient removal rates are impacted by more than one parameter, particularly at low concentrations. Brezonik[viii] includes in his discussions related to Monod and diffusion algal growth dynamics the recognition that more than one controlling factor may be involved, and that the Monod relationship may need to reflect this within the model, as noted in the following equation form:

$$\mu = \mu_{max.} \{[P]/(K_p+[P])\} \{[N]/(K_n+[N])\} \{[CO_2]/(K_C+[CO_2])\} \ldots \text{ Equation 11}$$

Noted in Table 4-2 are the results of Hanes plots for the four parameters considered. It is not surprising that total phosphorus shows good correlation with growth rate, as total phosphorus removal was used in calculating algae production. Nonetheless, it does appear reasonable that phosphorus is involved in growth rate determination, as noted in Figures 4-13 through 4-15. What is more difficult to explain are the negative values of K_s, most notable during the October to December period. Initially, this might be interpreted as indication of inhibition at high concentrations. However, at these concentrations (500-1,000ppb), there is no evidence within the literature that phosphorus inhibits algae production. Rather, it appears that what may be associated with this condition is the fact that growth calculated by phosphorus uptake during this period was an underestimate of actually measured growth—see Figures 3-5 and 3-6. The implication therefore is that during this time, the system drew its phosphorus from some source other than the water column—such as stores. As discussed previously, there is little space available for such stores within an ATS™, so it is suspected that the more likely explanation for these anomalies is data error.

The relationship over the adjusted POR between LHLR and growth rate appears rather clear, as noted in Figures 4-16 through 4-18, at least within the ranges studies. The correlations shown are reasonable, even with a few “outlier” data points. As noted, the relationships associated with nitrogen and carbon are not as clear.

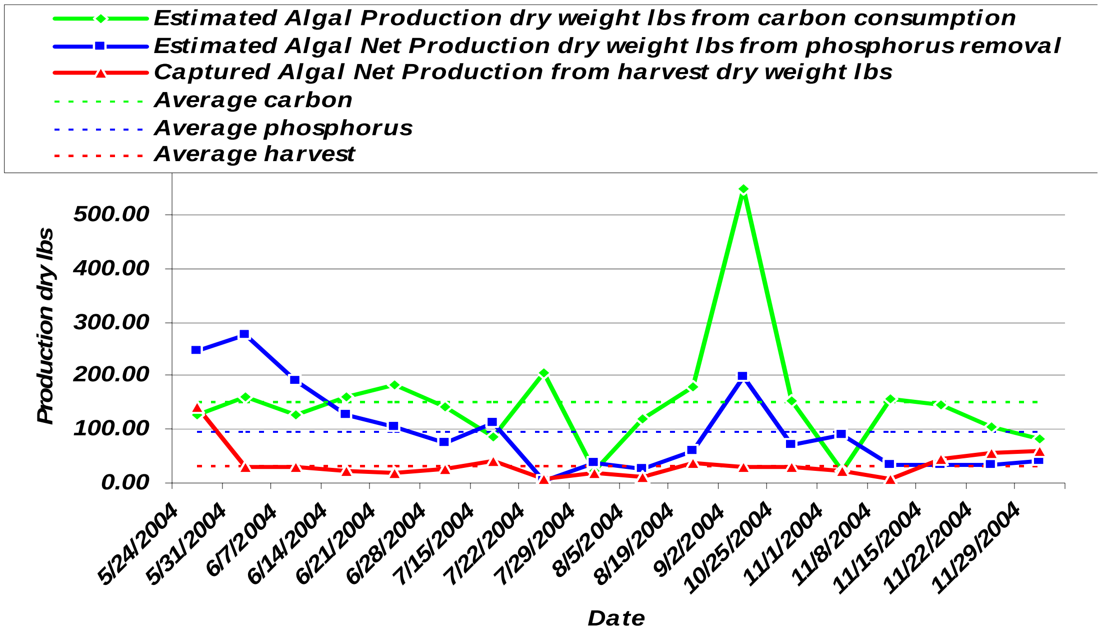


Figure 3-5: Trends in Carbon consumption based algal production estimates compared to actual harvest and phosphorus uptake based production projections Central single-stage ATS™ floway

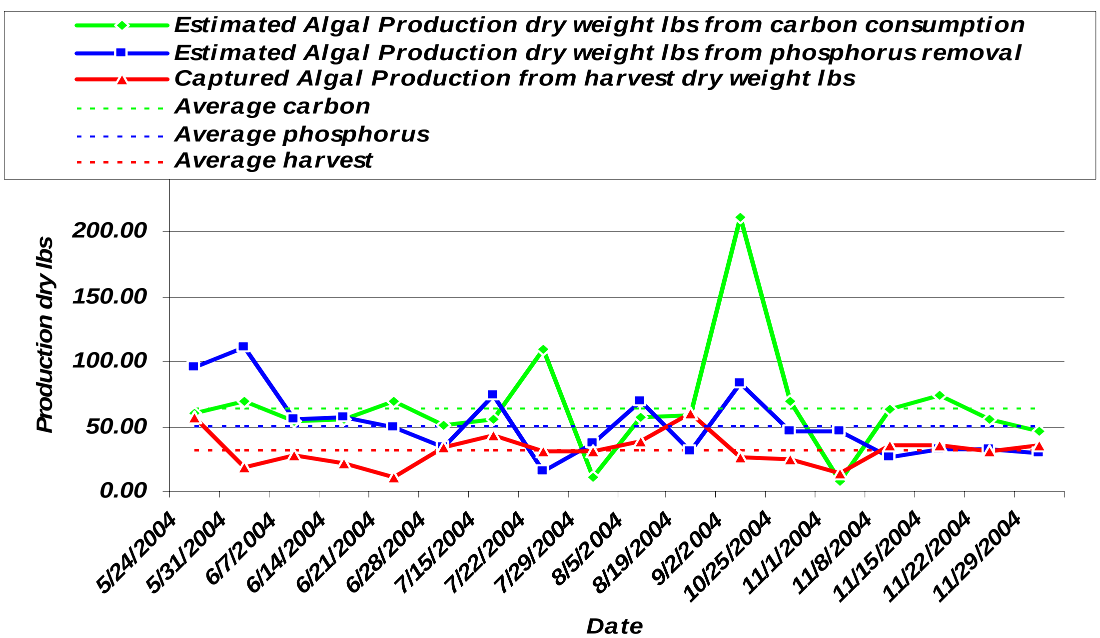


Figure 3-6: Trends in carbon consumption based algal production estimates compared to actual harvest and phosphorus uptake based production projections Central single-stage ATS™ floway

Table 4-1: Data set for adjusted POR

	Week ending	Period days	Average Water T C	Total P Average Concentration ppb	Total N Average Concentration mg/l	Available Carbon Average Concentration mg/l	LHLR gallons/ minute-ft	Estimated Algae Production dry grams	Calculated growth rate 1/hr
South Floway	5/17/2004	6	27.2	171	1.30	13.83	6.20	13,194	0.021
	5/24/2004	7	27.8	190	1.40	13.83	6.09	18,351	0.020
	5/31/2004	7	28.4	218	2.01	19.14	5.60	28,746	0.021
	6/7/2004*	7	29.2	178	1.90	15.24	3.90	13,681	0.015
	6/14/2004	7	27.1	116	1.70	17.98	4.41	14,627	0.019
	6/21/2004	7	30.2	106	1.48	18.56	5.62	12,103	0.013
	6/28/2004	7	31.4	75	1.49	16.23	2.69	13,488	0.012
	7/5/2004	3	32.3	57	1.70	14.07	5.12	5,277	0.018
	7/12/2004	7	31.1	72	1.30	14.07	4.44	4,094	0.007
	7/19/2004	7	30.4	48	1.19	11.90	4.82	463	0.002
	7/26/2004	7	29.4	61	1.05	12.16	4.15	6,947	0.011
	8/2/2004	7	29.5	55	1.21	22.68	4.52	6,874	0.011
	8/9/2004	7	28.3	57	0.96	11.55	3.61	4,204	0.010
	8/16/2004	5	29.7	63	1.20	22.81	5.82	6,670	0.015
	8/23/2004	7	30.4	336	2.20	30.72	3.37	18,905	0.015
	10/25/2004	7	28.0	885	1.28	25.58	5.47	6,959	0.013
	11/1/2004	7	28.3	830	2.11	11.74	2.95	3,324	0.009
	11/8/2004	7	28.2	715	2.63	26.33	6.48	3,912	0.009
	11/15/2004	7	24.8	625	1.57	25.46	4.93	5,260	0.015
	11/22/2004	7	24.3	500	2.01	21.53	4.82	2,245	0.010
	11/29/2004	7	24.7	300	1.11	17.09	4.90	16,022	0.025
Central Floway	5/17/2004	6	26.7	186	1.25	11.81	22.84	30,193	0.030
	5/24/2004	7	27.3	190	1.50	11.81	22.98	71,964	0.030
	5/31/2004	7	28.0	223	2.24	14.11	22.60	110,742	0.032
	6/7/2004*	7	29.1	178	1.90	11.27	25.11	79,193	0.026
	6/14/2004	7	27.3	129	1.79	13.54	24.55	56,162	0.029
	6/21/2004	7	30.2	119	1.53	13.35	23.40	45,956	0.021
	6/28/2004	7	30.9	88	1.54	11.98	19.14	34,307	0.018
	7/5/2004	3	31.5	65	1.26	11.17	26.51	26,807	0.036
	7/12/2004	7	30.5	77	1.30	10.37	18.30	16,849	0.015
	7/19/2004	7	30.5	48	1.15	18.04	19.57	1,910	0.005
	7/26/2004	7	29.6	67	1.10	9.88	16.96	20,676	0.017
	8/2/2004	7	30.2	66	1.19	15.47	19.52	15,628	0.015
	8/9/2004	7	28.4	58	0.96	15.62	14.21	16,114	0.018
	8/16/2004	5	29.1	70	1.12	15.76	22.72	19,803	0.025
	8/23/2004	7	30.2	346	2.21	28.94	11.78	64,722	0.023
	10/25/2004	7	27.5	880	1.28	17.65	16.47	24,019	0.022
	11/1/2004	7	27.3	815	2.05	10.59	17.97	30,617	0.024
	11/8/2004	7	27.5	710	2.17	18.03	17.22	13,906	0.018
	11/15/2004	7	24.9	630	1.81	17.82	17.14	14,583	0.024
	11/22/2004	7	23.4	490	1.94	16.00	17.03	15,984	0.028
	11/29/2004	7	24.4	335	1.09	12.84	17.33	22,940	0.029
	12/5/2004	6	23.3	240	1.52	12.84	18.16	26,852	0.040
North Floway	5/17/2004	6	27.0	171	1.25	11.66	10.52	22,410	0.026
	5/24/2004	7	27.5	210	1.60	11.66	10.71	18,990	0.020
	5/31/2004	7	28.2	223	2.19	13.99	9.56	46,102	0.025
	6/7/2004*	7	29.1	193	2.00	11.17	9.36	23,893	0.019
	6/14/2004	7	27.1	119	1.62	13.72	9.10	26,433	0.024
	6/21/2004	7	30.2	110	1.58	13.37	9.41	23,294	0.017
	6/28/2004	7	31.0	83	1.54	12.09	8.78	16,184	0.014
	7/5/2004	3	32.1	58	1.22	11.07	19.10	15,493	0.028
	7/12/2004	7	31.1	68	1.25	10.04	4.70	10,084	0.011
	7/19/2004	7	30.8	41	1.11	17.55	9.56	5,363	0.009
	7/26/2004	7	30.1	59	1.05	9.80	9.40	14,860	0.015
	8/2/2004	7	29.6	55	1.16	14.86	8.09	13,400	0.015
	8/9/2004	7	28.3	53	0.96	15.31	8.10	9,813	0.015
	8/16/2004	5	29.7	81	1.20	15.76	6.66	3,035	0.010
	8/23/2004	7	30.4	326	2.10	29.99	2.23	11,409	0.013
	10/25/2004	7	27.8	630	1.28	18.05	7.99	16,982	0.019
	11/1/2004	7	27.8	582	2.23	10.86	8.79	17,389	0.019
	11/8/2004	7	28.0	524	2.26	18.47	7.22	13,229	0.017
	11/15/2004	7	24.5	468	1.58	17.95	9.01	17,174	0.026
	11/22/2004	7	24.9	398	1.85	16.01	9.11	18,348	0.026
	11/29/2004	7	24.6	325	1.08	12.60	9.24	17,264	0.026

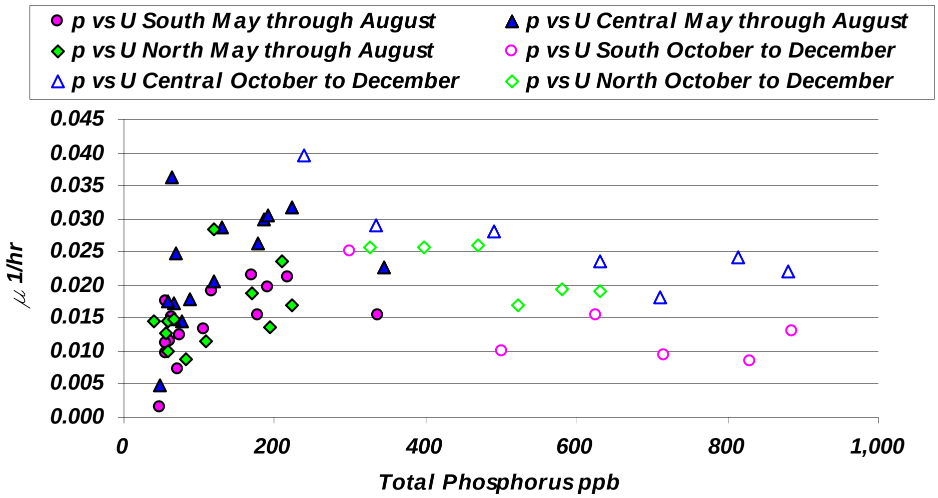


Figure 4-9: Total phosphorus Vs. calculated growth rate adjusted POR data set

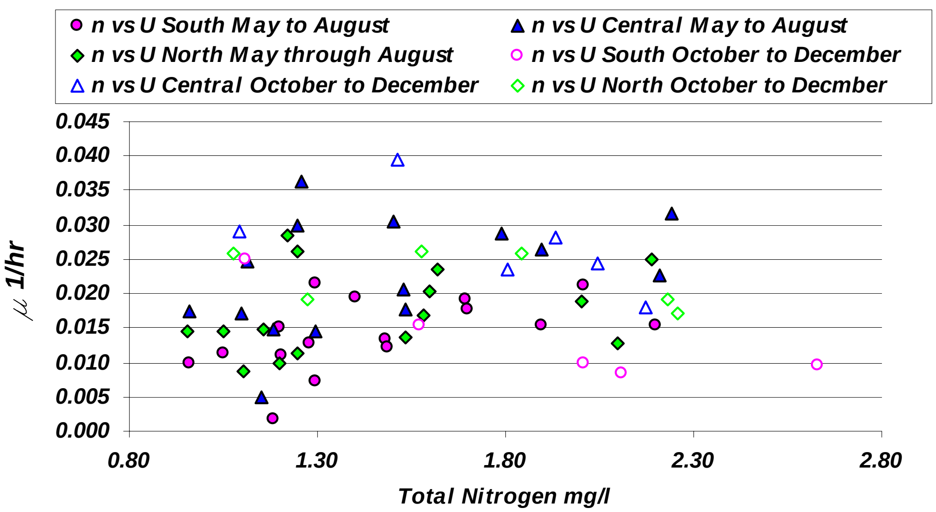


Figure 4-10: Total nitrogen Vs. calculated growth rate adjusted POR data set

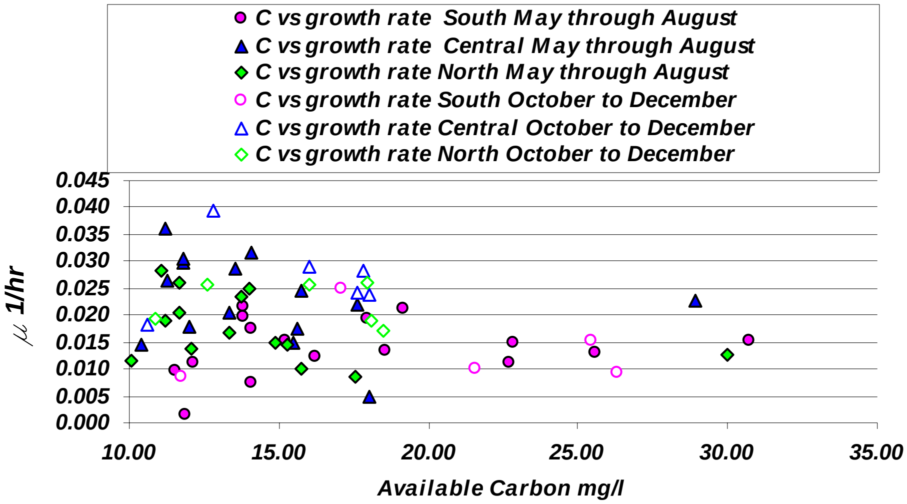


Figure 4-11: Available Carbon Vs. calculated growth rate adjusted POR data set

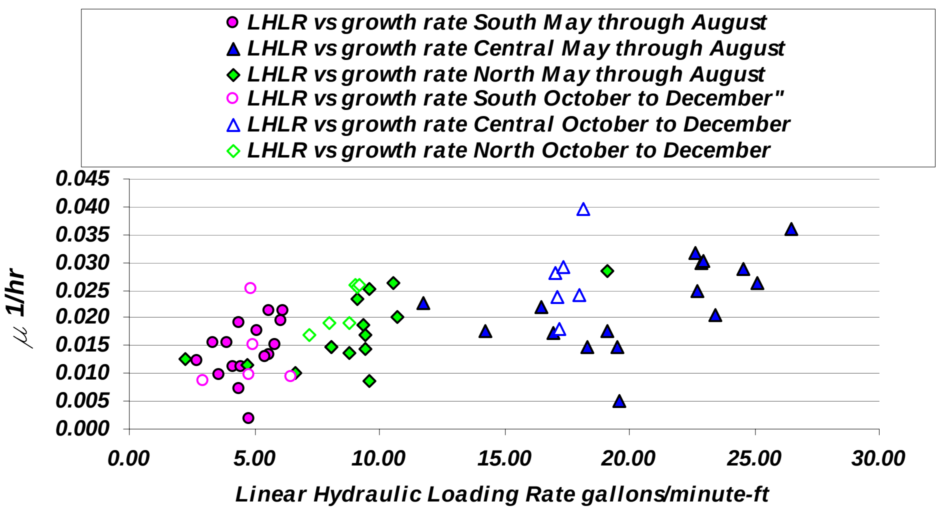


Figure 4-12: Linear Hydraulic Loading Rate Vs. calculated growth rate adjusted POR data set

Table 4-2: Results of Hanes analysis

Floway	Time Period	Parameter	r^2	μ_{max} 1/hr	K_s *
Combined	Total POR	TP	0.720	0.015	-15
Combined	May through August	TP	0.327	0.025	71
Combined	October to December	TP	0.740	0.015	-81
Combined	Total POR	TN	0.021	0.031	1.72
Combined	May through August	TN	0.002	-0.091	-11.04
Combined	October to December	TN	0.536	0.017	-0.32
Combined	Total POR	Available C	0.126	0.014	-0.27
Combined	May through August	Available C	0.078	0.016	3.16
Combined	October to December	Available C	0.590	0.013	-5.17
Combined	Total POR	LHLR	0.159	0.030	8.6
Combined	May through August	LHLR	0.147	0.029	9.5
Combined	October to December	LHLR	0.805	0.037	5.7

*** ppb for TP, mg/l for TC and Carbon, gpm/ft for LHLR**

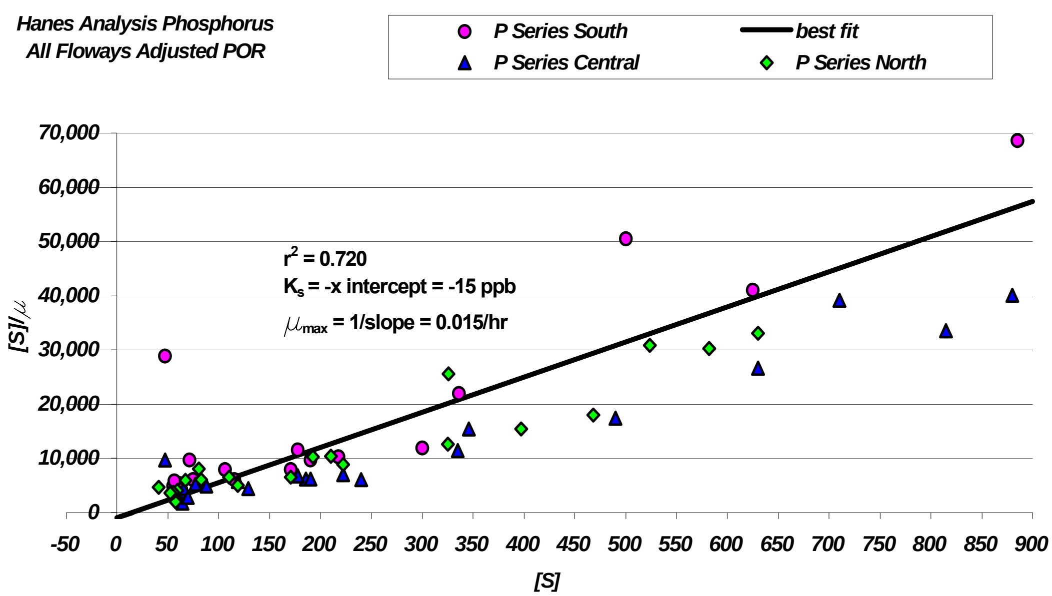


Figure 4-13: Hanes plot total phosphorus all floways over adjusted POR

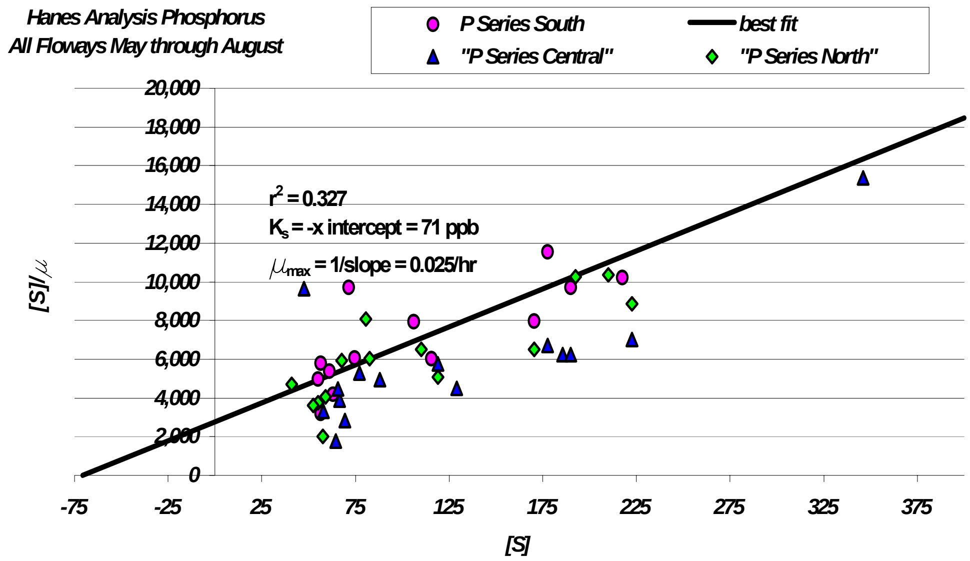


Figure 4-14: Hanes plot total phosphorus all floways May through August

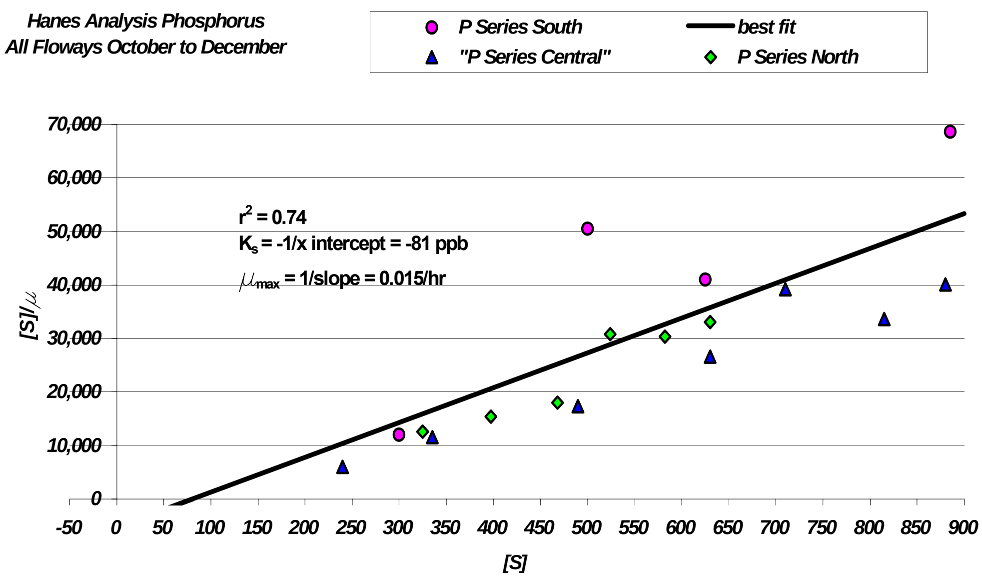


Figure 4-15: Hanes plot total phosphorus all floways October to December

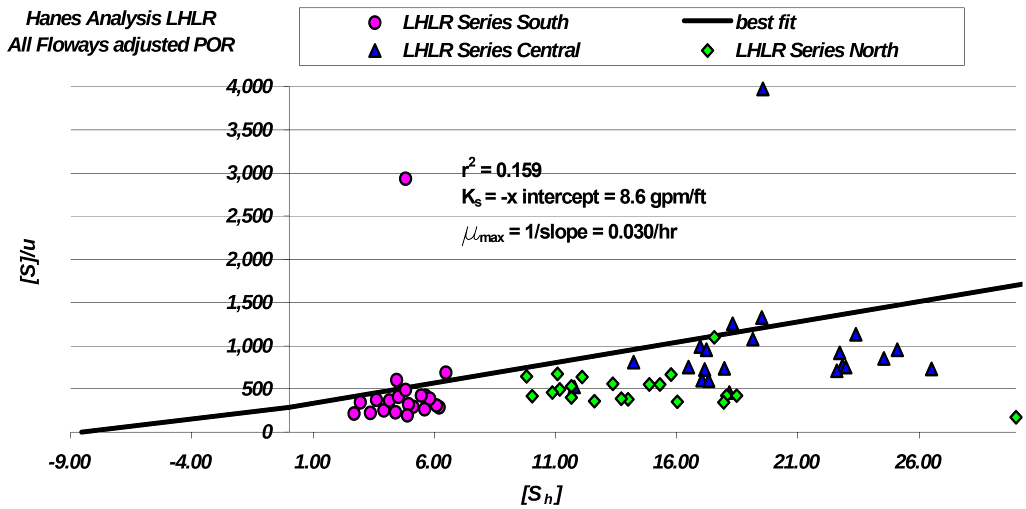


Figure 4-16: Hanes plot LHLR all floways over adjusted POR

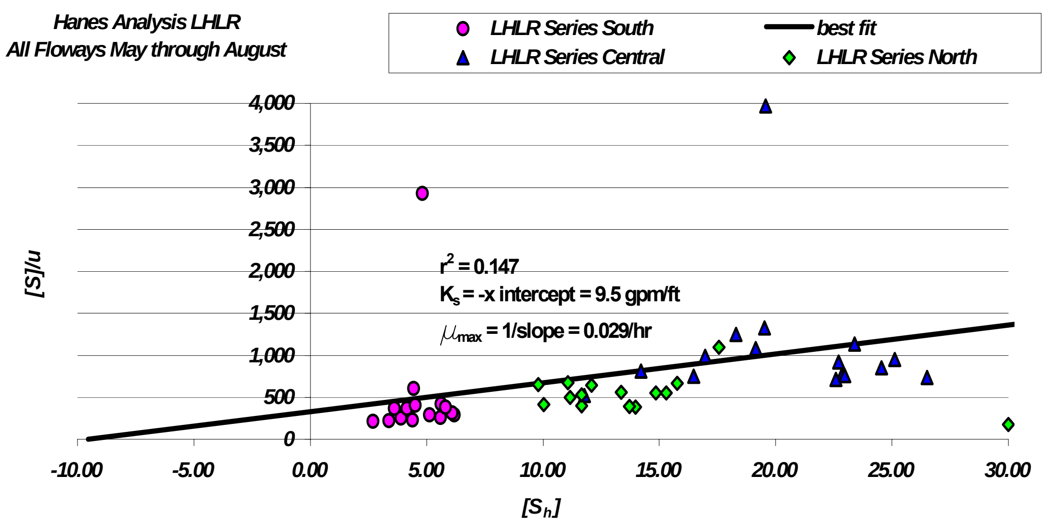


Figure 4-17: Hanes plot LHLR all floways May through August

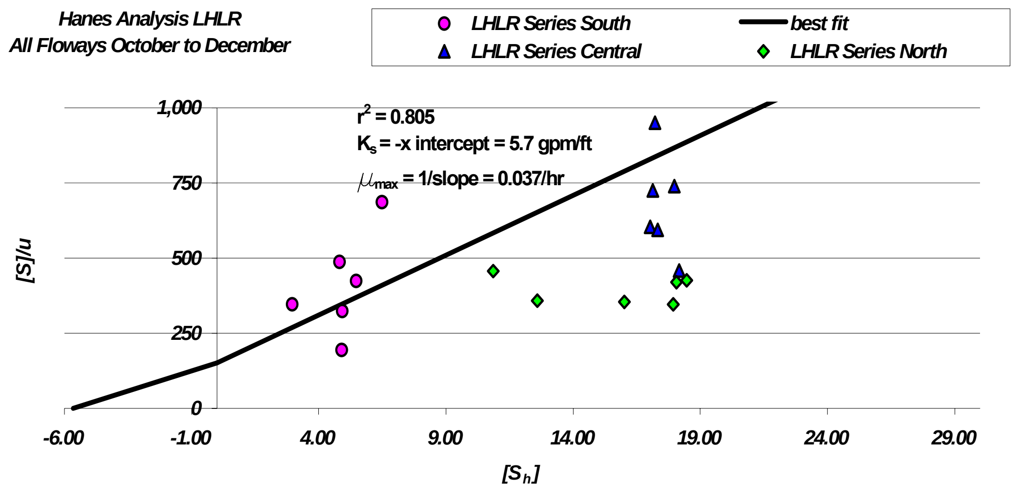


Figure 4-18: Hanes plot LHLR all floways October to December

The issue of the influence of flow rate and velocity upon algae growth rate has been extensively reviewed within the literature. Brezonik[ix] in a detailed discussion regarding the relative role of nutrient uptake within algae as influenced by both Monod dynamics and boundary layer transport through molecular diffusion, presents work done on models that include consideration of both phenomena. He notes that at high substrate [S] concentrations, boundary-layer diffusion control over growth rate becomes negligible. At low concentrations, however, diffusion influences can overwhelm the Monod kinetics, and uptake projections based solely upon the Monod growth equations without inclusion of diffusion influence can be higher than observed. He identifies a factor **1/(1+P')** as representative of the proportion of the total resistance to nutrient uptake caused by diffusion resistance, where:

$$P' = a(14.4\pi D_s r_c K_s)/V \quad \textbf{Equation 12}$$

When ***a*** = shape factor applied to algal cell shape

D_s = Fick's diffusion coefficient as substrate changes per unit area per unit time

r_c = algal cell radius

K_s = Substrate concentration when uptake rate ***v*** is ½ of maximum uptake rate ***V***

V = Michaelis-Menten substrate uptake rate mass per unit time

The Michaelis-Menten ***V*** may be seen in this case as analogous to the Monod maximum growth rate or μ_{max}, therefore it is reasonable to express the equation as:

$$P' = a(14.4\pi D_s r_c K_s)/\mu_{max.} \quad \textbf{Equation 13}$$

Brezonik includes this P' into the Monod relationship at low concentrations of S, resulting in the equation:

$$\mu = \mu_{max.}\ [P'/(P'+1)]S/K_s \quad \textbf{Equation 14}$$

It is noted then, the smaller P' the greater the influence of growth.

Observations regarding velocity influences relate to the general thickness of the boundary layer around the cell wall. Carpenter et al.[16] discuss the influence water movement has upon the thickness of the boundary layer. This is consistent with discussions offered by Brezonik who notes that "*turbulence increases nutrient uptake rates at low concentrations where diffusion limitations can occur*". He generally observed that at low concentrations Monod dynamics can be influenced by boundary layer conditions, and uptake rates may be lower than predicted by Monod kinetics. This is relevant when discussing the use of periphytic algae for reduction of total phosphorus to low concentrations, because passive systems such as PSTA which rely upon extensive areas and very low velocities, would be expected to be much more restrained by boundary layer thickness at low concentrations, which as noted by both Carpenter et al. and Brezonik, is inversely related to the gradient through which diffusion occurs. The ATS™ system by adding the influence of flow and turbulence can substantially enhance the uptake rate and production of the algal turf.

Turbulence and water movement therefore serve to increase the rate of substrate transport, and hence decrease the importance of diffusion. This quite logically is why the use of high velocities and turbulence (e.g. oscillatory waves) enhances algal nutrient uptake. Brezonik notes that in low nutrient conditions there exists a minimum velocity (u_{min}) at which diffusion limitation of nutrient uptake is avoided. He defines this mathematically as:

$u_{min} = (2D_s/r_c)\{(2/P')-1\}$ Equation 15

This means that at P' = 2, u_{min} = 0, and u_{min} increases as P' decreases. Values for P' of some algae species are provided, ranging from 0.33 to 680, but there is no discussion offered for assessing the cumulative influence of an algal turf community upon the general role of diffusion or how u_{min} might be determined on the ecosystem level. Rather, empirical information such as that provided by Carpenter et al. and work such as that done on the single-stage ATS™ floways can provide insight into the reaction of algal communities to velocity changes.

It is noteworthy that at low nutrient concentrations, adapted algae species would likely be characterized by a low K_s value. This is validated by Brezonik, who notes the difficulty in determining the controlling influence of nutrients upon algae production at low nutrient levels, as "*K_s may be below analytical detection limits—making it difficult to define the μ vs. [S] curve*." He includes some of the documented K_s values for several algae species associated with low nutrients. Phosphate appears as a limiting nutrient in several cases, with K_s values as low as 0.03 μM as PO_4, or about 3 ppb as PO_4, or just less than 1 ppb as phosphorus. As K_s is directly proportional to P', then it would not be unexpected that at low nutrient levels, P' would be comparatively small, and hence u_{min} comparatively large—the implication being that elimination of diffusion influence becomes very important, and hence flow velocity becomes an important design parameter. As noted, Kadlec and Walker[9] made reference to the influence of flow velocity upon the efficacy of PSTA systems. With velocities orders of magnitude greater within ATS™ systems, it becomes an even more essential design component with ATS™. The inclusion of higher velocities and oscillatory motion within the ATS™ operational protocol allows contemplation of much higher phosphorus uptake rates, which has broad economic implications.

One practical way to include flow in an operational model is to treat LHLR as a controlling parameter. It seems appropriate then to consider a growth model, as suggested by Brezonik, in which two factors are included in the Monod equation (see Equation 10). It seems reasonable to include both total phosphorus and LHLR in the case of this dataset. The parameters $\mathbf{K_s}$ and $\boldsymbol{\mu_{max}}$ can then be approximated through convergence to the lowest standard error between actual and projected total phosphorus concentration. Once the parameters are so calibrated with the Central Floway data, then the model reliability can be tested with data from the North and South Floways. This was done, applying the following relationship, as modified from Equation 9:

$$\mathbf{S_{pp} = S_{pi} - \{[S_t\{Z_o e^{\mu_{max}\,[\{S_{pa}/(Ksp+S_{pa})]\,[(Lp/(Khp+Lp)][24t]\,[}\,1/\Theta^{(Topt-T1)} - Z_o\}]/V_p\}} \qquad \textbf{Equation 16}$$

Where S_{pp} = projected effluent total phosphorus concentration for sampling period

S_{pi} = Influent total phosphorus concentration for sampling period

Z_o = Initial algal standing crop at beginning of sampling period

S_{pa} = Mean total phosphorus concentration across ATS™ for sampling period

K_{sp} = Monod half-rate coefficient total phosphorus

L_p = Linear Hydraulic Loading Rate for sampling period

K_{hp} = Monod half-rate coefficient LHLR

t = sampling period time in days

V_p = Volume of flow during sampling period

The result of the calibration run for the Central floway is shown in Table 4-3 and Figure 4-19. The parameter set which resulted in the best projection (lowest standard error=40.61 ppb) was μ_{max} = 0.04/hr, **K_{sp}** = 37 ppb, **K_{hp}** = 9.3 gpm/ft, **T_{opt}** = 29.9 ^oC and Θ = 1.10, with an initial standing crop of 10 dry-g/m^2.Using these values, the model was applied to the other two floways, as noted in Figures 4-20 and 4-21.

Table 4-3: ATSDEM Projection effluent total phosphorus Central Floway

$Z_{0\ dry}$-g	**1390**
Θ	**1.10**
T_{opt} ^oC	**29.9**
K_{sp} ppb	**37**
K_{sh} gpm/ft	**9.30**
μ_{max} 1/hr	**0.04**

	Week ending	Period days	Average Water Temperature C	Period Flow gallons	Sp Average P ppb	Sh LHLR gpm/ft	Estimated P tissue Content	Field Calculated Growth Rate	Projected Growth Rate	Influent Total P ppb	Effluent Total P ppb	Projected Total P
Central	**5/17/2004**	**6**	26.7	986,787	186	22.8	0.63%	0.026	0.017	211	160	184
	5/24/2004	**7**	27.3	1,204,631	190	23.0	0.63%	0.028	0.019	240	140	197
	5/31/2004	**7**	28.0	1,157,989	223	22.6	0.65%	0.030	0.020	305	140	245
	6/7/2004	**7**	29.1	1,139,115	178	25.1	0.63%	0.028	0.022	235	120	151
	6/14/2004	**7**	27.3	1,265,598	129	24.6	0.60%	0.026	0.018	164	94	133
	6/21/2004	**7**	30.2	1,237,320	119	23.4	0.59%	0.025	0.022	148	90	74
	6/28/2004	**7**	30.9	1,179,360	88	19.1	0.57%	0.023	0.021	110	66	53
	7/5/2004	**3**	31.5	964,656	65	26.5	0.56%	0.051	0.022	85	44	77
	7/12/2004	**7**	30.5	572,540	77	18.3	0.57%	0.019	0.019	99	55	15
	7/19/2004	**7**	30.5	922,204	48	19.6	0.55%	0.008	0.016	49	46	19
	7/26/2004	**7**	29.6	986,135	67	17.0	0.56%	0.020	0.016	82	51	53
	8/2/2004	**7**	30.2	854,905	66	19.5	0.56%	0.019	0.018	79	52	34
	8/9/2004	**7**	28.4	983,700	58	14.2	0.55%	0.019	0.013	70	46	54
	8/16/2004	**5**	29.1	716,421	70	22.7	0.56%	0.028	0.017	90	49	70
	8/23/2004	**7**	30.2	817,852	346	11.8	0.73%	0.027	0.021	422	270	317
	10/25/2004	**7**	27.5	830,325	880	16.5	1.05%	0.021	0.020	920	840	801
	11/1/2004	**7**	27.3	905,817	815	18.0	1.01%	0.023	0.020	860	770	754
	11/8/2004	**7**	27.5	867,933	710	17.2	0.95%	0.018	0.020	730	690	626
	11/15/2004	**7**	24.9	864,060	630	17.1	0.90%	0.018	0.015	650	610	605
	11/22/2004	**7**	23.4	858,542	490	17.0	0.81%	0.019	0.013	510	470	483
	11/29/2004	**7**	24.4	873,224	335	17.3	0.72%	0.021	0.014	360	310	332
	12/5/2004	**6**	23.3	784,534	240	18.2	0.66%	0.026	0.012	270	210	255

Mean TP Effluent actual ppb	**242**
Mean TP Effluent projected ppb	**251**
Standard error of estimate ppb	**40.61**

The model displayed reasonable, and conservative projections, and may be considered applicable for initial sizing of proposed facilities. Depending upon the level of performance demand placed upon the facility, the design engineer may want to include a contingency factor to cover the standard error, which ranged from 17% to 35%. Considering that the difference between the actual and projected mean effluent concentrations for the POR were so close, it is concluded that for long-term projections, the ATSDEM model is suitable for ATS™ programs that fall within the general water quality and environmental ranges studied. In some cases, particularly if there are significant differences in conditions, or when performance tolerances are small, "bench" scale testing may be a recommended pre-design exercise.

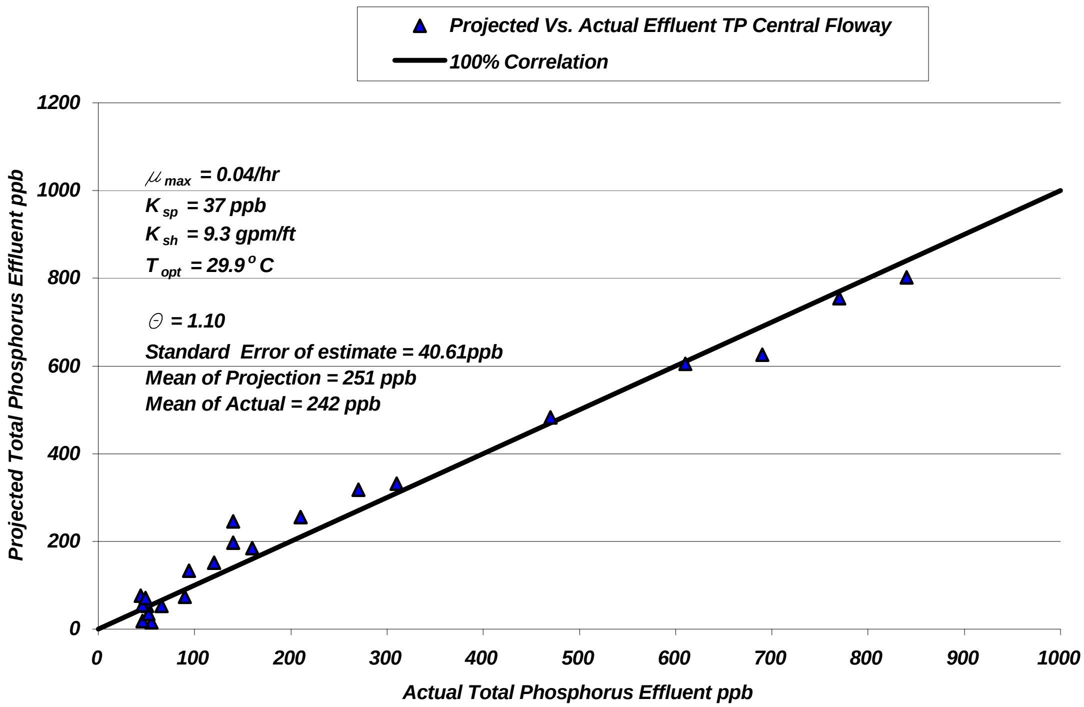


Figure 4-19: Actual Vs. ATSDEM Projected total phosphorus effluent concentration Central Floway

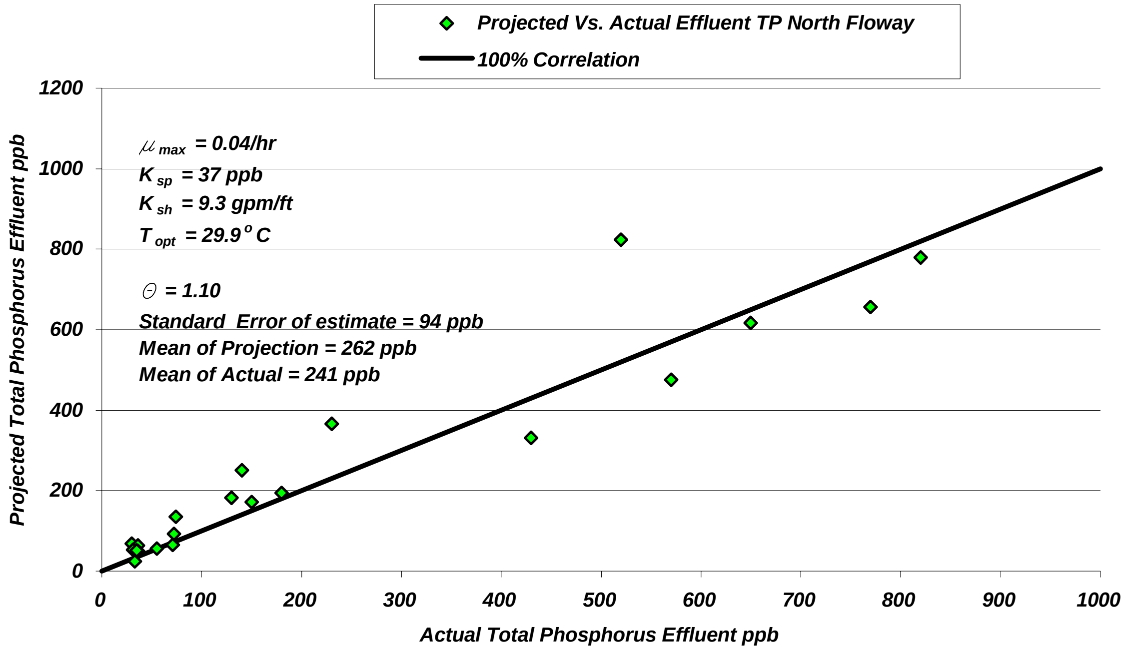


Figure 4-20: Actual Vs. ATSDEM Projected total phosphorus effluent concentration North Floway

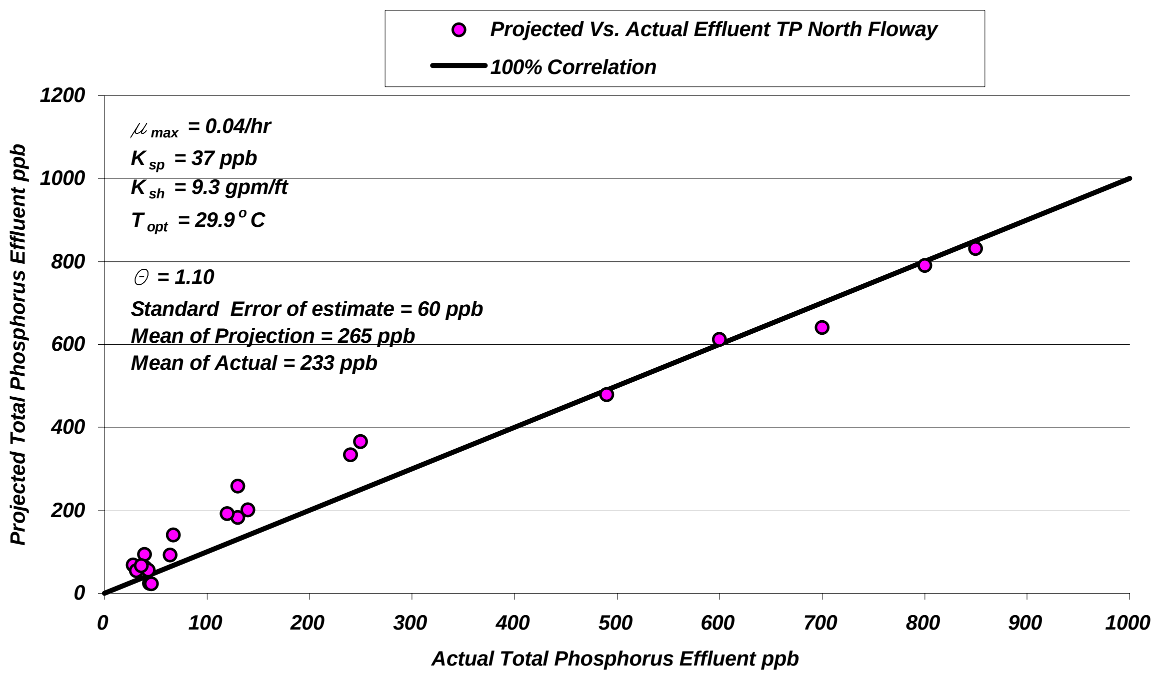


Figure 4-21: Actual Vs. ATSDEM Projected total phosphorus effluent concentration South Floway

While models such as ATSDEM are helpful in conducting conceptual level sizing of a proposed facility, and the various components associated with the proposed facility, and for projecting the rate of production and the harvesting needs, they assume that system operation is conducted such that the design provisions are sustained. As with most biological systems, the ultimate success and efficiency of a system relies heavily upon effective operational management, and the ability of a skilled operator to recognize, and sustain a healthy working biomass.

A Practical Excel Spreadsheet Based ATSDEM

While very complex computer models could certainly be developed for sizing and designing ATS™ systems, a practical spreadsheet model is typically the most helpful to the engineer at the conceptual and preliminary engineering level, and may well be all that is required, as long as design conditions are relatively predictable, and within ranges for which the model is developed. The general theory of function regarding ATS™ has already been described, with Monod growth kinetics, and diffusion boundary influences both incorporated into the basic algorithm. The basic premise for ATS™ is that 1) it is driven by photosynthesis, or primary productivity, and that sustaining high levels of productivity through frequent harvesting is essential and 2) the principal mechanism for removal of nutrients through an ATS™ is direct plant uptake, either through incorporation into tissue, luxury storage within cellular organelles, or precipitation/adsorption upon the cell wall.

Before proceeding with the refinement of a practical EXCEL based model, it is crucial that those involved in sizing and design, be even more sensitive to the importance of operational efficiency. The modeling includes assumptions that the system is harvested effectively and completely, with biomass removal complete. It has been observed that incomplete harvest or leaving residual mats of non-productive biomass on the floway can interfere with performance. Also, harvesting at improper frequencies can also result in poor performance. The general operational strategy is to maintain a consistent biomass level on the ATS™ at all times, and the modeling is based on the presumption that this is done. Algae that are not harvested properly can become senescent, as it proceeds towards another successional level. These senescent algae accordingly will interfere and compete with the uptake of water column associated nutrients, as they become a rudimentary "soil" for new plant communities—such as aquatic vascular plants, and pioneer transitional plants (e.g. Primrose willow and cattails). This new ecostructure becomes less dependent upon the water column as its nutrient source, which accordingly will retard performance. It is a critical operational component then that harvesting be used to "pulse stabilize" the ecosystem, and thereby avoid successional pressures. This general strategy is the foundation of all MAPS technologies, as well as heterotrophic based systems, such as activated sludge.

It is typical that the harvesting frequency for an ATS™ in warm season conditions will be about every seven days, meaning that the entire ATS™ floway is completely harvested every seven days. In the cooler season, this frequency will typically increase to every 14 days. ATSDEM projections are based upon a composite average condition for the entire floway. For example an average standing biomass, Z_{ave} represents the standing crop at anytime as dry-g/m^2 averaged over the whole ATS™ area. It is a function of the frequency of harvesting, and can be estimated through Equation 17.

$$Z_{ave} = \left(\sum_{m=1}^{n} Z_0 e^{24m\mu} \right) \Big/ n$$

Equation 17

Where **m** is the days since harvest, and **n** is the days between harvests.

It is recognized that any one section of the ATS™ may be providing better or less treatment than the model projection, but as an average, the model effluent estimate and actual composite effluent can be expected to be similar. This applies to any time period during the operation. While photosynthesis occurs only during the daytime, productivity projections are based upon a 24-hour period. While there may be some concern that nocturnal performance is well below diurnal performance, experience indicates that nutrient uptake does continue with the loss of sunlight, even if carbon fixation is discontinued.

While the model is based upon the assumption that direct nutrient uptake within the plant biomass is the sole removal mechanism, under certain conditions other phenomenon may also contribute—including luxury uptake; adsorption; emigration through invertebrate pupae emergence and predation; and chemical precipitation, both within the water column directly, and upon the surface of the algal cell wall. Some evidence of these factors is noted with the change in tissue phosphorus concentration with change in water column total phosphorus concentration, as noted previously. By incorporating the change in phosphorus concentration within the tissue, it is presumed that ATSDEM incorporates the influence of these other phosphorus removal mechanisms.

In the case of an ATS™, the velocity parameter is expressed as gal/minute-ft of ATS™ width, also known as the Linear Hydraulic Loading Rate or LHLR, as presented previously. The LHLR as discussed previously is incorporated into the ATSDEM equations. The LHLR converts to flow by multiplying by the ATS™ width. Width in this case does not refer to the short side of a rectangle, but rather the length of the influent headwall in which the flow is introduced to the ATS™. In actuality this "width" may well be larger than the ATS™ "length", which is the distance from the headwall to the effluent flume. Within the ATS™ velocity can be estimated using the Manning's Equation:

$$\mathbf{V = (1.49/n)r^{2/3}s^{1/2})} \quad \textbf{Equation 18}$$

Where **V** = velocity fps
n = Manning's friction coefficient
r = hydraulic radius = flow cross- section area/wetted perimeter
s = floway slope

However, the Manning's coefficient "**n"** will vary as the algal turf develops, and is harvested, and in addition, surging will create a predictable change in flow from zero to the something greater than u_{min} (Equation 15*)* during the siphon (surge) release. Actual velocity variations are best determined from field observations under different conditions (e.g. high standing biomass, pre-surge, post surge, etc.)

As applied to an ATS™, the Manning Equation can be simplified by first multiplying both sides of the equation by the flow area A, which is equal to the flow depth (d) in feet times the ATS™ width (w) in feet, or:

$$\mathbf{Q_{cfs}=Vdw = (1.49/n)dw)r^{2/3}s^{1/2}} \quad \textbf{Equation 19}$$

As the hydraulic radius r is flow area (A) over the wetted perimeter, then:

$$\mathbf{r = dw/(w+2d)} \quad \textbf{Equation 21}$$

Therefore:

$$\mathbf{Q_{cfs} = 0.00223(LHLR)w} \quad \textbf{Equation 22}$$

when **LHLR** is gallons/minute-ft. If **w** is set at 1 ft, then

$$\mathbf{LHLR = \{0.00332d^{5/3}s^{1/2}\}/[n(2d+1)^{2/3}]} \quad \textbf{Equation 23}$$

This allows for the flow depths to be established for specific Manning's "n" values and slopes, and accordingly, velocity can be estimated. These relationships are noted in Figure 4-21.

As noted, the higher the floway slope, the greater flexibility in terms of maintenance of a critical velocity—i.e. the velocity at which boundary layer disruption is complete. However, higher slopes require greater earthwork quantities and higher lifts.

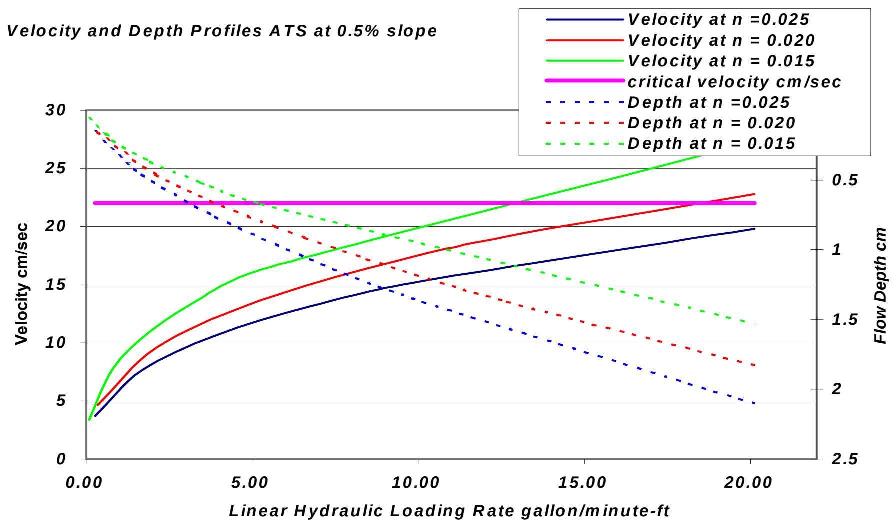
Down a floway then, the change in phosphorus concentration (dC_p/dt) may be expressed as:

$$dC_p/dt = S_t(dZ/dt)/\ q_t \quad \textbf{Equation 24}$$

Where $\mathbf{q_t}$=control volume over time increment

The change in floway length traversed by the control volume, with time, **dL/dt**, is expressed as:

$$dL/dt = vt \qquad \textbf{Equation 25}$$



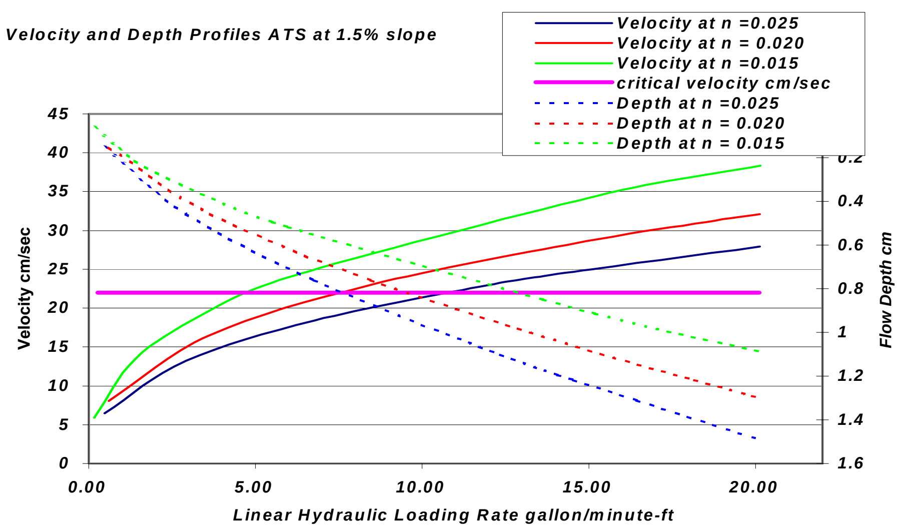


Figure 4-21: Velocity, LHLR and depth relationships as determined from Manning Equation

These relationships hold for a relatively short time sequence when $\mathbf{C_{t0}} \sim \mathbf{C_{t1}}$, e.g. one second. This then can be put into a spreadsheet to facilitate assessment of ATS™ performance using Equation 8 adjusted per Equation 15, under established K_s and μ_{max} values. The Manning relationship is incorporated into the model to allow estimation of Velocity.

The actual format for the ATSDEM spreadsheet model includes a front-end tutorial sheet, followed by a Design Parameter and Summary Worksheet, followed by a Z_{AVE} worksheet, and finally the Model Run Worksheet. These are presented within Appendix A. The example used for the model run is for a proposed system on the Kissimmee River with a flow of 26.5 MGD and an annual total phosphorus removal of 5,180 pounds. The Conditions and results for both warm and cool season associated with each Panel from the Design Parameter and Summary Worksheet are shown as Figure 4-22. A summary table is presented as Table 4-4.

Panel A Velocity Conditions

Floway slope (s)	Manning n	Manning Factor (1)	Manning Factor (2) Match	LHLR gpm/lf	LHLR cfs/lf	LHLR liters/sec-lf	Average flow depth (d) ft	Velocity fps	Flow length interval ft
0.005	0.02	0.008458	0.008458	20	0.045	1.280	0.06	0.75	0.75

Panel B Process Conditions Warm Season

Water T °C	Optimal T °C	Θ	K_{sp} as ppb TP	K_{sh} as LHLR gpm/ft	μ_{max} 1/hr	S_o ppb Total P	Harvest Cycle days	Z_{ave} dry-g/m²	Z_0 dry-g/m²	S^*_p Total Phosphorus ppb
28	30	1.10	40	4	0.04	150	7	82.73	8.00	30

Panel C Performance Warm Season

Control Time Seconds	Control Volume liter	Final Total P S_f ppb	Total Flow Time seconds	Total P percent removal	Floway Length ft	Areal Loading Rate TP g/m2-yr	Areal Loading Rate TP lb/acre-day	Areal Removal Rate TP g/m2-yr	Areal Removal Rate TP lb/acre-day	Average Production dry-g/m²-day	Area per time sequence m²
1	1.280	45	780	70%	582	110	2.70	78	1.89	37.35	0.069

Panel C Performance Cool Season

Control Time Seconds	Control Volume liter	Final Total P S_f ppb	Total Flow Time seconds	Total P percent removal	Floway Length ft	Areal Loading Rate TP g/m2-yr	Areal Loading Rate TP lb/acre-day	Areal Removal Rate TP g/m2-yr	Areal Removal Rate TP lb/acre-day	Average Production dry-g/m²-day	Area per time sequence m²
1	1.280	126	780	16%	582	110	2.70	18	0.43	8.20	0.069

Panel D System Design Cool Season

Total Flow mgd	Floway Width ft	Floway Area acres	Total P removed ton/period	Moisture % wet harvest	Moisture % compost	Period Wet Harvest tons	Period Dry Harvest tons	Period Compost Production wet tons	Performance Period days	μ_{ave} 1/hr
25	868	11.59	0.41	5%	40%	1,371	69	86	165	0.0082

Note: Inputs in Blue Print

Panel D System Design Warm Season

Total Flow mgd	Floway Width ft	Floway Area acres	Total P removed ton/period	Moisture % wet harvest	Moisture % compost	Period Wet Harvest tons	Period Dry Harvest tons	Period Compost Production wet tons	Performance Period days	μ_{ave} 1/hr
25	868	11.59	2.20	5%	40%	6,246	312	390	200	0.0188

Panel B Process Conditions Cool Season

Water T °C	Optimal T °C	Θ	K_{sp} as ppb TP	K_{sh} as LHLR gpm/ft	μ_{max} 1/hr	S_o ppb Total P	Harvest Cycle days	Z_{ave} dry-g/m²	Z_0 dry-g/m²	S^*_p Total Phosphorus ppb
18	30	1.10	40	4	0.04	150	14	41.54	8.00	30

Figure 4-22: Design Parameter and Summary Worksheet Kissimmee ATS™ 26.5 MGD

Table 4-4: ATSDEM summary 25 MGD Kissimmee ATS

	Warm Season	Cool Season	Combined Annual
Flow (MGD)	25	25	25
Width (ft)	868	868	868
Length (ft)	582	582	582
Area (acres)	11.59	11.59	11.59
Time Period (days)	200	165	365
Average Water Temperature on ATS™ (^{o}C)	28	18	23
Influent TP (ppb)	150	150	150
Effluent TP (ppb)	45	126	82
Period TP Removal (pounds)	4,400	820	5,220
Wet Harvest (tons)	6,246	1,371	7.617
Compost Production (tons)	390	86	476
TP Loading Rate (g/m^2-yr)	110	110	110
TP loading rate (lb/acre-day)	2.7	2.7	2.7
TP Removal Rate (g/m^2-yr)	78	18	51
TP Removal Rate (lb/acre-day)	1.89	0.43	1.23
Algal Production (dry-g/m^2-day)	37.4	8.2	24.2

[i] Walker, W.W. (1995) "Design basis for Everglades stormwater treatment areas" Water Resource Bulletin American Water Resources Association Vol 31 No. 4
[ii] The City of Orlando just recently had to remove over 500,000 cubic yard of organic sediment after 15 years of operation of the Orlando Easterly Wetland.

[iii] As described by Brezonik, P.L.(1994) *Chemical kinetics and process dynamics in aquatic systems,* CRC Press, Boca Raton, Fl pp 114-117
[iv] Brezonik, P.L. (1993) Chemical Kinetics and Process Dynamics in Aquatic Systems Lewis Publishers, Boca Raton, Fl pp 421-427 ISBN 0-87371-431-8
[v] Lineweaver, H and D. Burke (1934) "The determination of enzyme dissociation constants" *J.Am.Chem.Soc.* **56,** 568
[vi] Hanes, C.S. (1942) *Biochem. J.* , 26, 1406
[vii] Eadie,G.S (1942) *J/ Biol. Chem.* 146,85 ; Hofstee, B.H.J. (1959) *Nature* 184, 1296
[viii] Brezonik, P.L. (1993) Chemical Kinetics and Process Dynamics in Aquatic Systems Lewis Publishers, Boca Raton, Fl pp 507-509 ISBN 0-87371-431-8

[ix] Brezonik, P.L. (1993) Chemical Kinetics and Process Dynamics in Aquatic Systems Lewis Publishers, Boca Raton, Fl pp 513-525 ISBN 0-87371-431-8