STA-1W Algal Turf Scrubber® Pilot

Final Performance Report

Aug 13, 2008-Aug 13, 2009

Prepared for:

South Florida Water Management District
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EXECUTIVE SUMMARY

- The Algal Turf Scrubber® (ATS™) has been identified as a technology that could provide the SFWMD an additional tool for the cost effective removal and recovery of phosphorus within the Everglades ecosystem.

- The intent of the STA-1W ATS™ pilot study was to determine site specific ATS™ treatment performance based on water quality conditions of effluent from Stormwater Treatment Area (STA) 1W or STA-1W.

- The STA-1W ATS™ Pilot was operated for a period of 12 consecutive months. This Final Report covers the time period from the week beginning August 13, 2008 through the week ending August 13, 2009. Included in this Final Report is a summary and review of operational, water quality and vegetation data.

- The ATS™ system was operated at mean quarterly linear hydraulic loading rates of 18.9, 14.7, 14.5, and 12.9 gallons per minute per linear foot for Quarter 1 (Q1), Q2, Q3 and Q4, respectively.

ALGAL TURF SCRUBBER®

- The mean influent total phosphorus concentration for the study period including the system start-up period was 35 µg/L. The mean effluent total phosphorus concentration was 24 µg/L.

- Total phosphorus reduction for the 12-month project including the system start-up period was 33.3%.

- Total phosphorus areal removal rate for the Algal Turf Scrubber® during the study period including system start-up was 3.1 g/m^2/yr.

ALGAL TURF SCRUBBER® WITH 10-MICRON SOLIDS RECOVERY

- Separate effluent samples were collected in order to demonstrate the effect of effluent solids screening at 10 microns as would be provided in a full-scale system. The Algal Turf Scrubber® with 10-micron filter study began Nov. 19, 2008 and ran for the duration of the pilot project.

- Mean influent total phosphorus during this period was 31 ug/L and mean effluent total phosphorus was 15 ug/L.

- Total phosphorus reduction for the Algal Turf Scrubber® with 10-micron solids recovery was 49.9%.

- The Algal Turf Scrubber® with 10-micron solids recovery achieved an outflow total phosphorus concentration of 10 ug/L or less in 7.9% of the weekly samples and an outflow total phosphorus concentration of 11 ug/L or less in 26.3% of the weekly samples.

- Total phosphorus areal removal rate for the Algal Turf Scrubber® with 10-micron solids recovery was 4.0 g/m^2/yr.

ALGAL TURF SCRUBBER® DESIGN MODEL (ATSDEM) PROJECTIONS

- After calibration, the ATSDEM model as applied for the 12 month period, showed effluent phosphorus and nitrogen concentrations, and phosphorus areal removal rate projections in close agreement with actual data.

Parameter	**ATSDEM Model Projections 12-month Average**	**Actual (Field) Data 12-month Average**
Effluent Total Phosphorus Concentration (µg/L)	22	22
Phosphorus Areal Removal Rate (g/m^2-yr)	3.34	3.43
Effluent Total Nitrogen Concentration (mg/L)	2.36	2.37

SECTION 1. PROJECT BACKGROUND

PILOT SYSTEM DESIGN

The STA-1W Algal Turf Scrubber® (STA-1W ATS™) Mobile Pilot Unit project was conducted in accordance with Contract #4600001289, between the South Florida Water Management District (SFWMD or District) and HydroMentia, Inc., dated February 29, 2008. The Algal Turf Scrubber® has been identified as a technology that could provide the SFWMD an additional tool for the cost effective removal and recovery of phosphorus within the Everglades ecosystem. In developing the pilot system design, the central consideration was the need to optimize phosphorus load reductions with a secondary goal of reducing the effluent phosphorus concentration towards the numerical goal of 10 ppb—the concentration designated as that level required to avoid an “imbalance in the natural populations of aquatic flora or fauna”[1].

The intent of the STA-1W ATS™ pilot study was to determine site specific ATS™ treatment performance based on water quality conditions of effluent from Stormwater Treatment Area (STA) 1W or STA-1W.The results will be used to (i) verify algal turf productivity and nutrient reduction projections developed in preliminary Algal Turf Scrubber Design Model (ATSDEM) analyses and (ii) optimize the design of a full-scale Algal Turf Scrubber® Phosphorus and Nitrogen Load Reduction Control Facility. A cross-sectional drawing of the pilot scale ATS™ system is shown as Figure 1 and General Location and Site Location Maps are provided as Figures 2 and 3.

The pilot system design features included a floway length of 1200 feet sloped at 0.5%; a width of one foot, and a hydraulic loading rate of as much as 97.8 cm/d (20 gallons/minute). The pilot unit was situated along the effluent canal of STA-1W, directly west of Cell 5B.

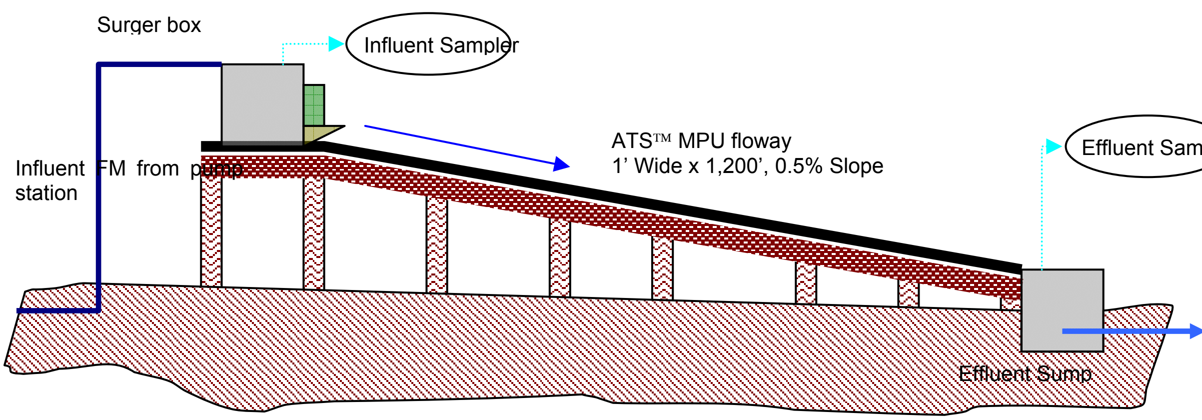
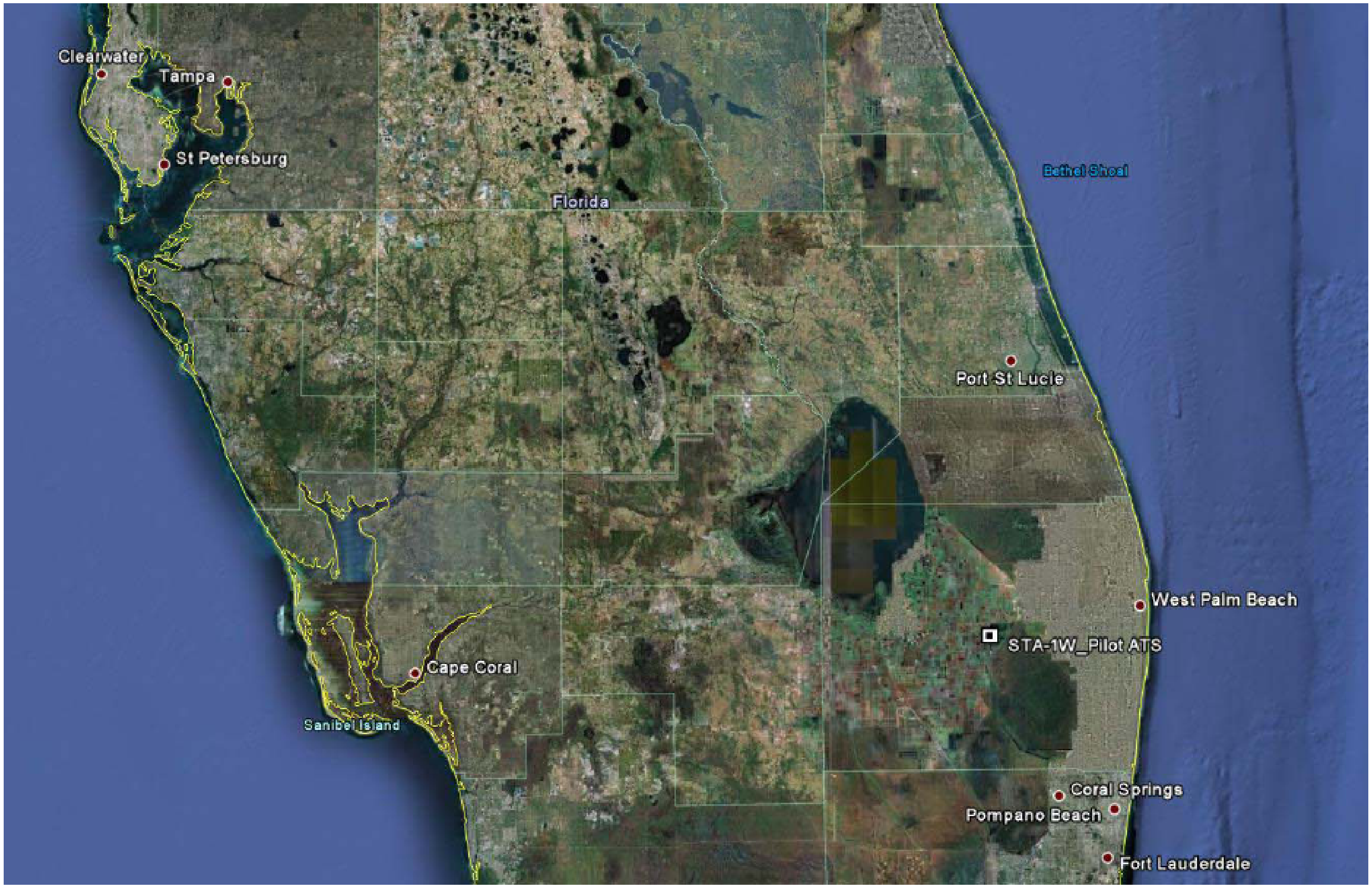


Figure 1. Cross section of Pilot Scale STA-1W ATS™ system. (Not to scale)

[1] The development of the 10 ppb total phosphorus standard began with the settlement agreement between the State of Florida and the U.S. Government from a 1988 law suit *U.S. Government vs South Florida Water Management District* Case No. 88-1886 Civ-Hoveler, Oct 11, 1988, and continuing through the implementation of provisions within the 1994 Everglades Forever Act (*Fla Sta 373.4592).*



HydroMentia, Inc. 3233 SW 33rd Road, Suite 201 Ocala, Florida 34474 Corporate: 352.237.6145 Engineering: 352.615.7188 www.hydromentia.com	**Algal Turf Scrubber® Phosphorus and Nitrogen Load Reduction System**	ATS™ PILOT GENERAL LOCATION MAP	SCALE: 1" = 1.17 Miles DATE: Apr 25, 2008

Figure 2. STA-1W ATS™ Pilot General Location Map

HydroMentia, Inc. 3233 SW 33rd Road, Suite 201 Ocala, Florida 34474 Corporate: 352.237.6145 Engineering: 352.615.7188 www.hydromentia.com	**Algal Turf Scrubber® Phosphorus and Nitrogen Load Reduction System**	ATS™ PILOT SITE LOCATION MAP	SCALE: 1" = 1.17 Miles DATE: Apr 25, 2008

Figure 3. STA-1W ATS™ Pilot Site Location Map

PILOT SYSTEM DESIGN OPTIMIZATION – FLOWAY LENGTH AND SOLIDS RECOVERY SYSTEMS

Optimization of the Algal Turf Scrubber® technology for any project is dependent on site-specific conditions and treatment objectives. Client goals can range from achieving the most cost-effective pollutant load reduction ($/lb-pollutant removed); maximizing percent pollutant removal; or achieving the lowest possible pollutant outflow concentration. Dependent on the client's treatment objectives, facility design and operational parameters such as floway length, hydraulic loading rate, and outflow filtration and solids recovery are adjusted to provide the most cost-effective system specifically designed to meet the client's goals.

As originally proposed, the ATS™ pilot project was intended as a field investigation specific to treatment performance associated with nonpoint source stormwater runoff from agricultural operations in the Everglades Agricultural Area (EAA), with location on an existing farm canal system, with a primary objective of maximizing cost-effective phosphorus load reduction ($/lb-pollutant removed). This initially proposed ATS™ system included a 600' ATS™ floway without secondary solids recovery.

During the pilot system site selection process, the decision was made to change the source water from agricultural nonpoint source runoff to Post-STA outflow (effluent). This changes the system from a Post-Best Management Practice (Post-BMP) or Pre-STA treatment system to a Post-STA treatment system, and accordingly changed the objectives of the pilot program. While optimization of cost-effective phosphorus load reduction remained important, additional emphasis was now clearly placed on achieving the lowest possible phosphorus outflow concentration—with the goal of 10 ppb total phosphorus as referenced in the previous section.

A detailed discussion and rationale for an optimal Post-STA Algal Turf Scrubber® system design is provided in the report titled Evaluation of the Algal Turf Scrubber® Managed Aquatic Plant System (MAPS) as an Advanced Treatment Technology for Everglades Protection dated October 7, 2004 (854 pp). The report provided a cost analysis of the Algal Turf Scrubber® technology in compliance with the guidelines set forth by the SFWMD's Supplemental Treatment Standards of Comparison (STSOC). The STSOC process developed specifically for the purpose of comparing various treatment technologies for Everglades' application.

In the 2004 report, the recommended design for a Post-STA Algal Turf Scrubber® treatment system included a 1500' floway length and an outflow solids recovery system that included a second stage 10-micron microscreen or disc filter as part of the solids recovery process. The 10-micron microscreen offered the benefit of increased algal solids recovery, thus producing lower outflow phosphorus concentrations—recognizing that these residual algae solids would contain notable amounts of phosphorus. A similar solids recovery system which included the use of a second stage 10-micron microscreen was employed at the S-154 Algal Turf Scrubber® system in the northern Lake Okeechobee watershed (Illustration 1).

Illustration 1. Hydrotech Model 1704 Discfilter (10 micron) at S-154 Algal Turf Scrubber® system in Okeechobee County, Florida.

In a Post-STA application such as the STA-1W ATS™ pilot, while phosphorus load reduction remains a priority, greater emphasis is placed on achieving the lowest possible outflow phosphorus concentration. To achieve the lowest possible outflow phosphorus concentration, the pilot ATS™ floway length and solids recovery system design are critical. However, due to budget limitations, no additional monies were available to increase length of floway to the recommended 1500', or add the second stage 10-micron microscreen.

Pilot System Optimization - Floway Length

To address the additional emphasis on maximizing percent phosphorus removal and achieving the lowest possible phosphorus outflow concentration, HydroMentia proposed extending the ATS™ pilot floway length from 600' to 1200'. The proposed revision to the design was approved by the SFWMD and HydroMentia assumed all additional costs associated with extending the floway length within the existing project budget. The revised 1200' pilot system, while 20% less than the recommended 1500' length, provides field data that can be used to verify performance projections and cost estimates as provided in the 2004 STSOC analysis.

Pilot System Optimization - Solids Recovery

To simulate treatment performance of the pilot ATS™ with a 10-micron microscreen for effluent solids recovery, filtered and unfiltered grab samples were collected weekly at the influent and effluent starting in November 2008.

SECTION 2. OPERATIONS

A primary objective of the STA-1W ATS™ Pilot study was to assess the relationship between in-situ water quality, environmental conditions and ATS™ efficiency. Assessment of operational dynamics includes consideration of climatic conditions, flow rates, and solids management, as well as water quality. During the Pilot Study, operational procedures such as flow rate and harvest frequency were manipulated to achieve maximum phosphorus load reduction while minimizing outflow phosphorus concentration. These operational changes were made in an effort to determine optimal ATS™ system design for total phosphorus reduction for a full-scale facility associated with the outflow from a Stormwater Treatment Area (STA) within the Everglades Ecosystem.

MONITORING PERIOD / PERIOD OF RECORD (POR)

The STA-1W ATS™ Pilot was operated by HydroMentia for a period of 12 consecutive months. For reporting purposes, the project will be defined in terms of four quarters (Table 1). This Final Report covers the time period from the week beginning August 13, 2008 through the week ending August 13, 2009. Included in this Final Report is a summary and review of operational, water quality and vegetation data.

Table 1. Date ranges for quarterly reporting periods for the STA-1W ATS™ Pilot.

Quarter	Begin Date	End Date
Q1	August 13, 2008	November 19, 2008
Q2	November 20,2008	February 18, 2009
Q3	February 19, 2009	May 20, 2009
Q4	May 21, 2009	August 12, 2009

SYSTEM START-UP

When operation of an Algal Turf Scrubber® system is initiated, some time is required for development of a viable, sustainable 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 & Stabilization Phase:</u> System start-up is initiated with the introduction of continuous flow to the Algal Turf Scrubber® Floway. During the start-up and stabilization phase, the algal turf community proceeds through ecological succession toward a sustainable algal turf community.

(2) <u>Fully Operational Phase:</u> Algal Turf Scrubber® system is fully operational when a sustained, mature algal turf community is established and maintained in conjunction with routine biomass recovery on the floway. An algal turf community may be considered mature when periodic harvesting serves to preserve its ecological complexity and stability. A mature algal turf associated with a fully-operational system is an interactive 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 system operator shall define the system as fully operational when the following conditions are met:

- *A sustained, mature algal turf community is present over 90% of the floway surface area*
- *A sustained, mature algal turf is established and maintained through periodic harvesting for a minimum period of 30 days*
- *Average algal turf standing crop*[2] *as dry-g/m^2 does not deviate substantially over a 90 day period*

The duration of the Start-up & Stabilization Phase is dependent on environmental conditions that include nutrient concentration, water temperature, solar radiation, etc. Initial start-up is associated with the establishment of attached algal turf biomass on the floway surface. 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, *cyanobacteria,* and unicellular green algae, as well a full compliment of bacterial and fungal communities, and invertebrate grazers, detritivores and predators.

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. This optimal density has found to vary based on environmental conditions, and it is important that this optimal density be determined during the course of any pilot investigation.

Based on these considerations, quantification of the average or mean algal biomass standing crop may therefore be employed as a general measurement of alga turf development. Dependent upon inflow water quality conditions, solar intensity and water temperature, an average algal turf standing crop of 20 to 150 dry-g/m^2 can serve as an initial indicator of transition from the Start-up Phase to the Stabilization Phase. If, following a harvest after this initial growth, the turf responds with quick recovery and increased productivity, and progresses steadily to the optimal density, then the operator can be confident that the system has reached a mature, sustainable dynamic.

It should be noted that the projected start-up period does not fully denote the period necessary to establish a mature algal turf community representative of the fully operational phase, but it does provide a general guideline as to how the duration of the start-up period may influence treatment performance of the pilot study.

ANALYSIS OF FLOWS

During Q1, the design flow-rate of 20.0 gpm was maintained with the exception of a pumping failure which occurred during the week ending Sept. 3, 2008. Mean measured flow rate was 18.9 gpm for Q1 (mean daily flow of 27,329 gpd). Flow rates were reduced during Q2, to a mean of 14.7 gpm (21,133 gpd) in an effort to determine whether lower flow would result in greater concentration reduction.

Because of the low available head at the effluent end, it was found that in-line flow meters were not reliable; therefore effluent flow is calculated as measured influent flow, plus rainfall contributions, minus reductions from historical regional ET rates for the applicable month. Areal removal rates are based on measured influent flows and calculated effluent flows. Weekly measured influent and calculated effluent flows are shown in Table 2.

At the beginning of Q2, two operational adjustments were implemented to optimize the system for total phosphorus concentration reduction.

The first operational adjustment included a flow rate reduction from approximately 20 gpm to approximately 14.5 gpm. The intent of the flow reduction was to increase flow residence time, potentially increasing phosphorus uptake and precipitation onto the algal biomass. Mean TP concentration

[2] Average algal turf standing crop is defined as the mean of each days projected standing crop for an entire period between harvests, when specific growth rate for the harvest period is applied for each day, and the initial standing crop is assumed to be 10% of the ending standing crop on the day of the previous harvest.

reduction during Q1 was 26.2%, while mean TP concentration reduction during Q2 was 44.6%, indicating that lower hydraulic loading rate increased percent nutrient removal. It should be noted that influent TP concentration and water temperature were lower during Q2 than during Q1, which would typically be expected to reduce removal efficiency; providing further support for a direct relationship between increased concentration reduction and reduced hydraulic load.

The second operational adjustment involved monitoring grab samples collected at the ATS™ pilot influent and effluent, and filtering these samples using a 10-micron filter. The filtering process provides an assessment of performance for an ATS™ system with a 10-micron microscreen. As previously discussed, a 10-micron screen is typically recommended for ATS™ applications where achieving the lowest possible outflow phosphorus concentration is a primary objective.

During Q3, mean flow rate was 14.3 gpm. On April 1, the effluent box became blocked with algae, preventing discharge. Additionally, the canal level on that date was above the elevation of the sample riser, resulting in overflow to the sample station. Heavy accumulated solids were noted in the sample riser and composite sample bottle on 4/8 and 4/15 and 4/22 as well. A mesh screen was placed in the effluent box on 4/22/2009 to reduce the occurrence of large particulates getting into the sample riser, in simulation of a flex rake—a component of a full scale system. During this period, grab samples were collected weekly for total phosphorus analysis at the influent and effluent and have been used to evaluate system performance for this period of heavy accumulation of solids.

During Q4, mean flow rate was 12.9 gallons per minute (gpm). Between 5/27/09 and 7/8/09, the intake line became periodically clogged with submerged vegetation, reducing flows to the system. This was due to increased discharges from STA-1W which resulted in increased vegetation within the effluent canal. On 6/24/2009, the intake strainer was lost on the autosampler, resulting in heavy solids deposition in the sample bottle, therefore, grab samples were used to represent system conditions for that week. On 7/1/09, no water was delivered to the system due to a brief power outage and failed check valve. The system was without flow for approximately 3 days, which caused the algal turf to completely dry-out. However, notable recovery was observed the following week and throughout the rest of the quarter.

Table 2. Total Flow and Weekly Flow Rates to the STA-1W ATS™ Pilot Project.

Week Ending	Measured Influent Flow (gal)	Calculated Effluent Flow (gal)	Influent Flow Rate (gpm)
8/20/2008	23,600	22,584	2.3
8/27/2008	134,800	135,138	13.4
9/3/2008	170,500	170,928	16.9
9/10/2008	221,649	222,077	22.0
9/17/2008	223,825	223,183	22.2
9/24/2008	214,228	213,212	21.3
10/1/2008	227,708	227,124	22.6
10/8/2008	212,730	215,512	21.1
10/15/2008	199,776	200,314	19.8
10/22/2008	213,273	212,876	21.2
10/29/2008	220,753	219,795	21.9
11/5/2008	205,943	206,052	20.4
11/12/2008	205,435	204,796	20.4
11/19/2008	183,272	182,633	18.2
11/25/2008	163,052	162,504	18.9
12/3/2008	195,279	194,910	17.0
12/10/2008	165,328	164,810	16.4
12/17/2008	151,009	150,678	15.0

Week Ending	Measured Influent Flow (gal)	Calculated Effluent Flow (gal)	Influent Flow Rate (gpm)
12/23/2008	120,096	119,578	11.9
12/30/2008	136,557	136,039	13.5
1/7/2009	155,483	154,849	13.5
1/14/2009	147,326	146,841	14.6
1/21/2009	143,276	142,642	14.2
1/28/2009	140,276	139,642	13.9
2/4/2009	141,795	141,431	14.1
2/11/2009	140,500	139,762	13.9
2/18/2009	139,820	139,082	13.9
2/25/2009	138,831	138,093	13.9
3/4/2009	137,895	136,911	13.8
3/11/2009	138,986	138,002	13.7
3/18/2009	137,938	137,028	13.7
3/25/2009	139,104	138,868	13.8
4/1/2009	166,320	167,797	16.5
4/8/2009	146,160	145,018	14.5
4/15/2009	137,088	136,320	13.6
4/22/2009	146,160	145,916	14.5
4/29/2009	143,136	141,994	14.2
5/6/2009	160,272	158,706	15.9
5/13/2009	136,080	135,337	13.5
5/20/2009	139,104	139,408	13.8
5/27/2009	126000	126080	12.5
6/3/2009	132,048	133,208	13.1
6/10/2009	140,112	139,028	13.9
6/17/2009	142,128	141,044	14.1
1/21/2009	143,276	142,721	13.6
6/24/2009	103,824	105,732	10.3
7/1/2009	108,996	110,182	10.8
7/8/2009	111,888	111,578	11.1
7/15/2009	144,144	143,610	14.3
7/22/2009	119,952	121,138	11.9
7/29/2009	159,264	158,954	15.8
8/5/2009	134,064	133,422	13.3
8/12/2009	134,064	135,292	13.3
		Q1 Mean	**18.9**
		Q2 Mean	**14.7**
		Q3 Mean	**14.5**
		Q4 Mean	**12.9**

* Pump outage

SECTION 3. WATER QUALITY AND TREATMENT PERFORMANCE

GENERAL

The effluent from STA-1W, which served as the influent to the pilot system may generally be characterized as a moderately to highly mineralized freshwater (average conductivity of 936 µS/cm), with near-neutral to slightly alkaline pH (7.53 annual average), of low nutrient content with low to moderate color, and minimal turbidity and presence of suspended solids The nutrient balance related to nitrogen and phosphorus indicated by a ratio of 76.9 based upon total nitrogen and phosphorus concentrations (N:P) is suggestive of a comparative abundance of nitrogen. However, the ratio of what is considered readily available phosphorus and nitrogen as ortho-phosphorus and nitrate and nitrite nitrogen was noted to be considerably lower at 14.1 as an average[3]. This ratio reflects a higher degree of balance between nitrogen and phosphorus available for algal turf productivity. The issue of nutrient dynamics associated with the algal turf productivity patterns is discussed in more detail in the following sections.

The STA-1W effluent was comparatively high in alkalinity, averaging 186 mg/L as $CaCO_3$ for the study period. The pH for this period averaged 7.53. Under these conditions, the water contains sufficient quantities of available carbon[4] to support expected levels of photosynthesis associated with algal turf productivity, and accordingly the water is well buffered against wide pH fluctuations often associated with high photosynthetic activity. In summary, while the STA-1W effluent is comparatively low in nutrients, based upon known water quality characteristics, it is well suited to support robust development of a sustainable algal turf community.

PHOSPHORUS DYNAMICS

Algal Turf Scrubber®

Total Phosphorus

For the 12-month study period, including the start-up period, the mean influent total phosphorus (TP) concentration[5] was 35 µg/L and the mean effluent TP was 24 µg/L. This represents a 33.3% concentration reduction based on weekly samples. Mean monthly influent and effluent total phosphorus concentrations for the period are shown in Figure 4, with weekly influent and effluent total phosphorus concentration and percent concentration reduction shown in Figures 5 and 6, respectively. A summary of total phosphorus results for weekly composite samples are noted in Table 3. Total phosphorus analysis for composite and grab samples (both filtered and unfiltered) are included in Table 4.

Q1 mean influent TP concentration was 46 µg/L and mean effluent TP was 35 µg/L, resulting in a 26.2% reduction in TP concentration for the first 13 weeks of start-up operations . Q2 mean influent TP concentration was 30 µg/L and mean effluent TP was 18 µg/L, resulting in a 41.3% reduction in total phosphorus concentration .

On 12/10/2008, 12/24/2008 and 1/7/2009 (Q2 period), there was contamination of the effluent composite samples caused by settled solids, which were visible at the sampling station. Consequently, an effluent riser was installed on 1/14/2009. With installation of the riser, there was a noticeable decrease in

[3] Ammonia nitrogen which also would be considered an available form, was not included in the monitoring plan. Historically the ammonia nitrogen levels have been comparatively low within the STA-1W effluent. The potential influence of ammonia nitrogen is discussed within the section" Nitrogen Dynamics"

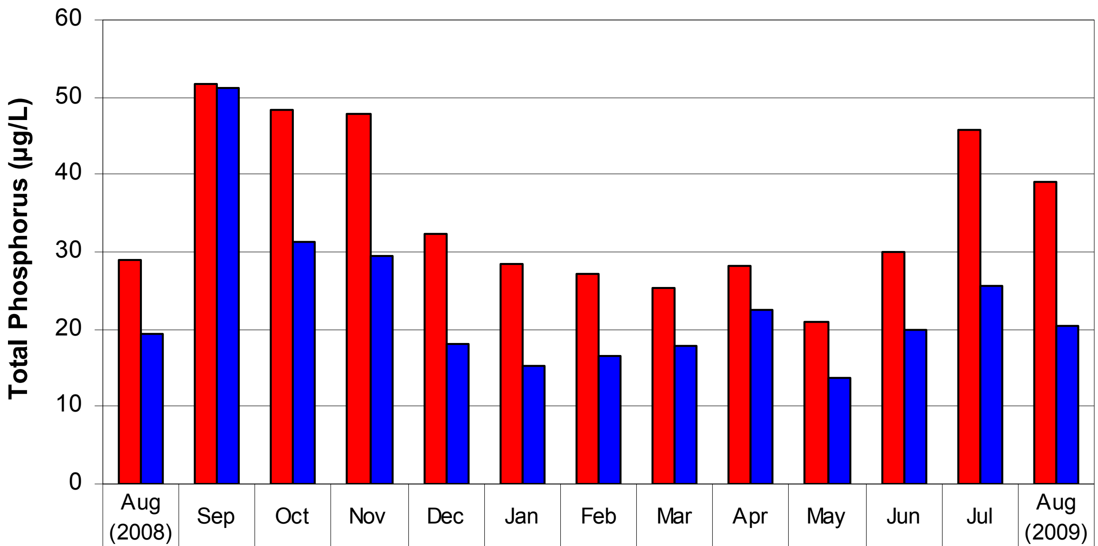
[4] The issue of carbon availability and its relationship to pH and Alkalinity is discussed in detail within the S-154 Pilot ATS™-WHS™ Aquatic Plant Treatment System Final Report (2005) Contract C-13933 SFWMD pgs. 129-134, with reference to analysis conducted by Saunders, G.W., F.B. Trama and R.W. Bachman (1962) "Evaluation of a modified C^{14} 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.

[5] All data presented in this section is based upon unfiltered influent and effluent samples.

suspended solids at the effluent sampling point, and effluent TP was consistently below influent TP. These values represent statistical outliers, thus influent and effluent grab sample values have been used to represent system conditions for those weeks.

Q3 mean influent total phosphorus (TP) concentration was well below the previous two quarters at 25 µg/L and mean effluent TP was 19 µg/L, resulting in a 24.4% mean reduction in phosphorus concentration based upon weekly samples. Also, during May of Q3 there was a discrepancy between total phosphorus values for composite samples analyzed by Jupiter Laboratories (Jupiter, FL) and those analyzed at the SFWMD laboratory. As advised by the Florida Department of Environmental Protection Quality Assurance, the samples were analyzed three times by Jupiter Laboratories, and a mean of the results is presented to represent water quality for this period.

Q4 mean influent total phosphorus (TP) concentration was 38 µg/L and mean effluent TP was 22 µg/L, resulting in a 42.5% mean reduction in phosphorus concentration based upon weekly samples.



	Aug (2008)	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug (2009)
Influent	29	52	48	48	32	29	27	25	28	21	30	46	39
Effluent	20	51	31	30	18	15	17	18	23	14	20	26	21

Figure 4: Monthly mean inflow and outflow total phosphorus concentrations for STA-1W ATS™ Pilot.

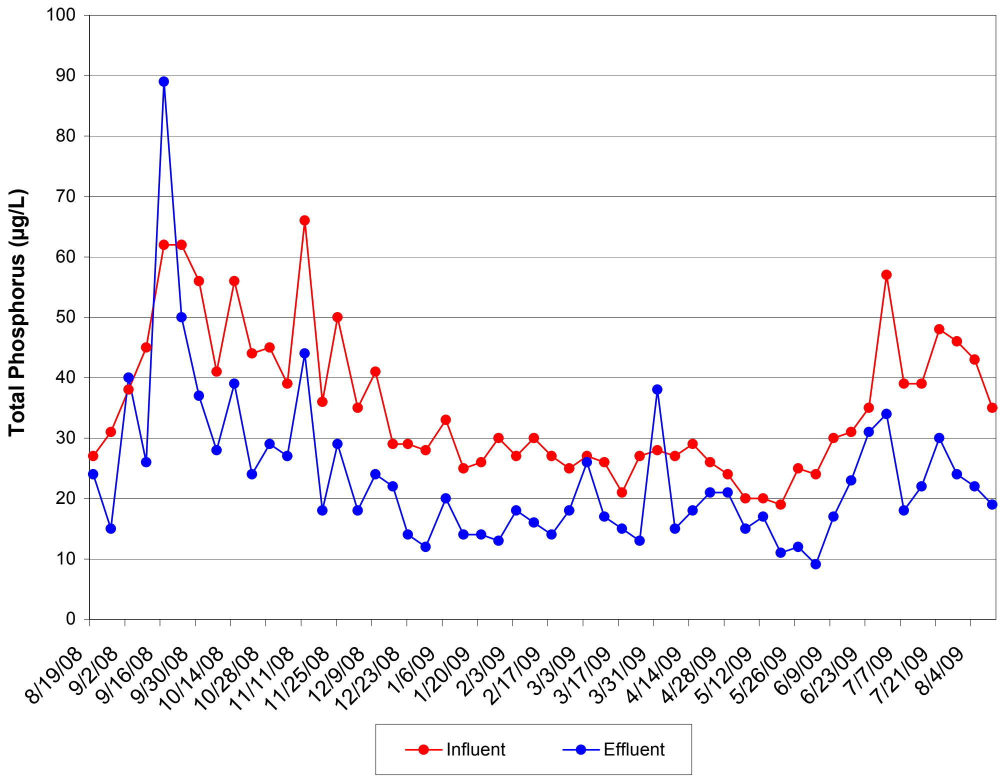


Figure 5: Weekly inflow and outflow total phosphorus concentrations for STA-1W ATS™ Pilot.

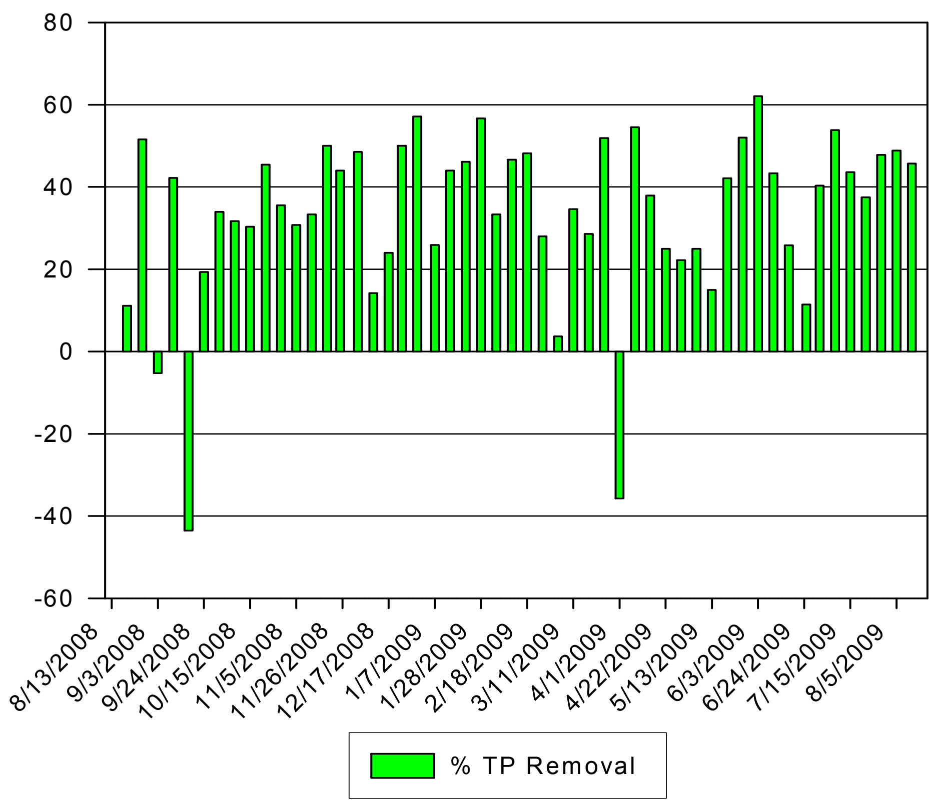


Figure 6: Weekly inflow and outflow total phosphorus percent reduction for STA-1W ATS™ Pilot.

Table 3: Influent and Effluent Data for Weekly Composite Total Phosphorus for the Study Period

	TP			
Sample Date	Influent (µg/L)	Effluent (µg/L)	% Reduction	Areal Removal Rate (mg/m^2-d)
8/20/2008	27	24	11.1	0.46
8/27/2008	31	15	51.6	10.43
9/3/2008	38	40	-5.3	-1.74
9/10/2008	45	26	42.2	20.50
9/17/2008	62	89	-43.5	-28.86
9/24/2008	62	50	19.4	12.62
10/1/2008	56	37	33.9	20.47
10/8/2008	41	28	31.7	13.33
10/15/2008	56	39	30.4	16.54
10/22/2008	44	24	45.5	20.79
10/29/2008	45	29	35.6	17.15
11/5/2008	39	27	30.8	12.06
11/12/2008	66	44	33.3	22.05
11/19/2008	36	18	50.0	16.05
11/25/2008	50	29	42.0	16.69
12/3/2008	35	18	48.6	16.12
12/10/2008	28*	24*	41.5	13.68
12/17/2008	29	22	24.1	5.16
12/23/2008	28*	14*	51.7	8.77
12/30/2008	28	12	57.1	10.62
1/7/2009	27*	20*	39.4	9.86
1/14/2009	25	14	44.0	7.88
1/21/2009	26	14	46.2	8.37
1/28/2009	30	13	56.7	11.59
2/4/2009	27	18	33.3	6.22
2/11/2009	30	16	46.7	9.59
2/18/2009	27	14	48.1	8.86
2/25/2009	25	18	28.0	4.69
3/4/2009	27	26	3.7	0.66
3/11/2009	26	17	34.6	6.02
3/18/2009	21	15	28.6	3.99
3/25/2009	27	13	51.9	9.42
4/1/2009**	28*	38*	-35.7	-9.88
4/8/2009**	27*	15*	44.4	12.53
4/15/2009**	29*	18*	37.9	7.68
4/22/2009**	26*	21*	19.2	4.81
4/29/2009	27	21	22.2	4.07
5/6/2009	20 (A)	15 (A)	25.0	3.65
5/13/2009	20 (A)	17 (A)	15.0	2.33
5/20/2009	19(A)	11 (A)	42.1	5.23
5/27/09	25	12	52.0	7.94

	TP			
Sample Date	**Influent (µg/L)**	**Effluent (µg/L)**	**% Reduction**	**Areal Removal Rate (mg/m^2-d)**
6/3/09	24	9	62.1	9.49
6/10/09	30	17	43.3	8.92
6/17/09	31	23	25.8	5.63
6/24/09	34*	31*	8.8	1.22
7/1/09	57	34	40.4	11.96
7/8/09	39	18	53.8	11.42
7/15/09	39	22	43.6	11.94
7/22/09	48	30	37.5	10.29
7/29/09	46	24	47.8	17.02
8/5/09	43	22	48.8	13.72
8/12/09	35	19	45.7	10.28
Mean Q1	**46**	**35**	**26.2**	**10.85**
Mean Q2	**30**	**18**	**41.3**	**9.03**
Mean Q3	**25**	**18**	**24.4**	**8.46**
Mean Q4	**38**	**22**	**42.5**	**9.99**
Annual Mean	**35**	**24**	**33.3**	**8.5**

*Value representative of grab sample
** Composite effluent sample site visibly contaminated
(A) Value reported is mean of 3 determinations
Values in parentheses indicate mean when potentially contaminated, and questionable laboratory result samples are removed from the dataset
Annual Mean based upon values in parenthesis as applicable

Ortho and Organic Phosphorus

For the 12 month study period, readily available phosphorus, in terms of ortho-phosphate (O-PO_4), averaged 16 µg/L for the influent, and 9 µg/L for the effluent. For Q1, O-PO_4 averaged 31 µg/L for the influent, and 17 µg/L for the effluent. For Q2, O-PO_4 averaged 12 µg/L for the influent, and 7 µg/L for the effluent. For Q3, mean influent O-PO_4 concentration was 10 µg/L and effluent was 8 µg/L. For Q4, mean influent was 10 µg/L and effluent was 8 µg/L.

Based upon averaged concentrations for the period, Ortho-P represented approximately 46% of influent total phosphorus and approximately 38% of the effluent total phosphorus for the project duration. Ortho-PO_4 represented approximately 67% of influent total phosphorus, and approximately 49% of effluent total phosphorus during Q1; 40% of influent total phosphorus and 39% of effluent total phosphorus for Q2; 40% of influent total phosphorus and 42% of effluent total phosphorus during Q3 and 26% of influent total phosphorus and 36% of effluent total phosphorus for Q4.

It is noteworthy, if the total phosphorus is understood to be the sum of organically bound phosphorus and ortho-phosphorus, that the percentage of ortho-phosphorus within the influent and effluent were not significantly different, for if only ortho-phosphorus is biologically available it would be expected that this percentage would drop considerably in the effluent as a result of selective uptake within the algal biomass. As noted in Table 5, while ortho phosphorus does appear to be preferentially removed, there is significant organic phosphorus reduction as well. The implication is that phosphorus dynamics within the

ATS™ floway is much more complex than just direct uptake of ortho phosphorus. This is an observation that was also noted during the 2003-2005 S-154 study[6].

Removal of organic phosphorus could be facilitated either by adsorption or settling of particulate organic phosphorus, or by conversion of organic phosphorus to ortho-phosphorus by actions of certain enzymes such as phospho-diesterase[7]. Because the suspended solids are low within the STA-1W effluent, it would appear more likely that enzymatic activity is involved.

Within the Everglades the removal of organic phosphorus is very important, as the concentrations of organic phosphorus within the STA-1W effluent, and presumably of future STAs as well, are significantly above the 10 µg/L standard. Consequently, it is imperative that organic phosphorus removal be a critical component of any treatment regime. This has been recognized for some time by HydroMentia, and this is why within the previously referenced STSOC study, effluent filtration was considered to be an important polishing process for any ATS™ effluent. This would be particularly important if it were confirmed that the algal turf community not only facilitated enzymatic reduction of organic phosphorus, but also served to convert ortho phosphorus to organic phosphorus, held within the turf biomass, and that a small but significant portion of this converted organic phosphorus were sloughed within the effluent. This sloughed material therefore would be susceptible to removal via micro-screening. In November, 2008 it was decided to invest the effort to test the veracity of this process dynamic, by collecting both influent and effluent grab samples to be tested for total phosphorus before and after filtering at 10 microns. The results are presented in the following subsection.

Algal Turf Scrubber® with 10-Micron Solids Recovery

As noted, filtering of a weekly collected grab sample commenced on November 19, 2008 ,and continued throughout the remainder of the study period (8/12/09). The weekly results for phosphorus are included in Table 3. A summary is noted in Tables 5 and 6. The filtering of these samples was done as a simulation of treatment that would result from application of a 10-micron microscreen to the ATS™ effluent (see Illustration 1). Non-preserved, grab samples, with less than 24-hour holding time were used rather than acidified composite samples, in order to protect the stability of any organic particles, which would be vulnerable to lysing and disintegration within the acidified composite samples.

For the period November 19, 2008 through August 12, 2009, the mean outflow for 10-micron screened samples based upon averaged quarterly values as shown in Table 5 was 15 µg/L. Mean monthly influent and effluent total phosphorus concentrations of 10-micron screened samples for the period are shown in Figure 7, with weekly influent and effluent total phosphorus concentration and percent concentration reduction shown in Figures 8 and 9, respectively.

As a result of the 10 micron filtration, total phosphorus percent removal increased, and the outflow total phosphorus concentration decreased. Total phosphorus percent removal when ATS™ effluent filtration was included was 50.0%, which is 18.7 percentage points higher than that achieved by the ATS™ without filtration, based upon quarterly averages of grab samples. Additional concentration reduction of 6 µg/L is achieved when compared to un-filtered effluent grab samples based upon average quarterly samples (16 µg/L for filtered samples vs. 22 µg/L for unfiltered effluent samples). Mean areal removal rate based on these data is 10.3 mg/m^2-d (3.6 g/m^2-year) for filtering after ATS™ treatment as compared to 8.5 mg/m^2-d (3.1 g/m^2-year) for treatment by the ATS™ alone without filtering.

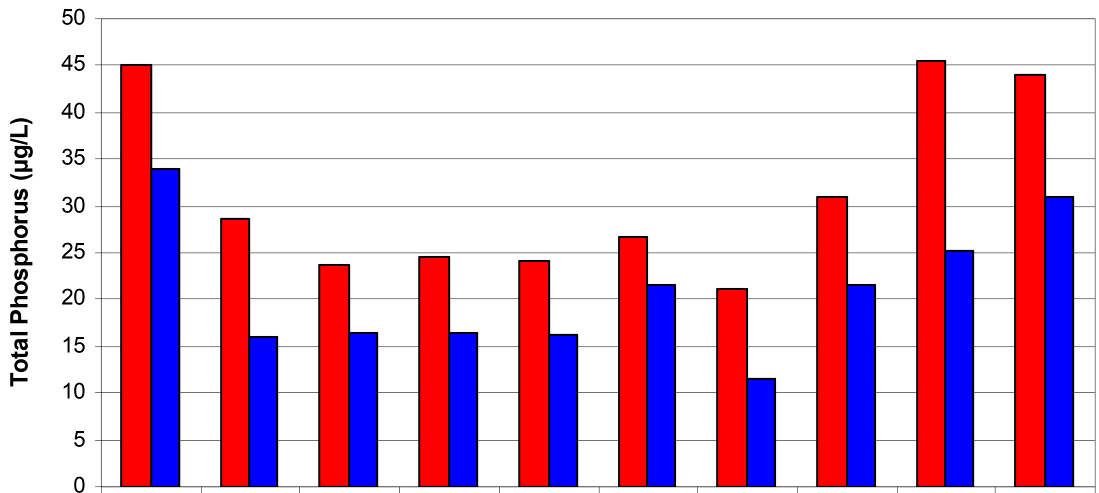
As had been suspected (see previous subsection) particulate phosphorus within the ATS™ effluent was considerably higher on a percentage basis than for the influent—27% versus 6% respectively based upon average quarterly samples. This strengthens the argument that the algal turf community does slough a

[6] Note discussion of phosphorus dynamics within the S-154 Pilot ATS™-WHS™ Aquatic Plant Treatment System Final Report (2005) Contract C-13933 SFWMD pgs. 90-103,

[7] There is a thorough review of phophatase enzymes within the paper: Reddy, K.R., M. Clark ,J. Jawitz, T. DeBusk, M. Annable, W. Wise, S. Grunwald (2003) "Phosphorus retention and storage by isolated and constructed wetlands in the Okeechobee basin. Florida Department of Agriculture and Consumer Services pp 63-82.

small but significant amount of tissue, and that the phosphorus contained within this sloughed tissue is largely organic phosphorus.

If the findings from this exercise were applied to the average values for the full study period for the non-filtered composite samples, the phosphorus dynamic would be expected to follow closely the model shown as Figure 10, where a microscreen process included for polishing the ATS™ effluent (Microscreen assisted ATS™). Of note is that the organic phosphorus would be reduced to below the 10 µg/L standard. Consequently, removal of the residual available phosphorus would facilitate satisfaction of this standard. Based upon these findings it is recommended that a microscreen unit, or a similarly effective process, be included as the final process of a first stage ATS™ Unit, and that when applied to the STA-1W effluent, total phosphorus concentrations can be expected to achieve an average of 16-18 µg/L, assuming STA-1W effluent quality in terms of total phosphorus does not deviate upward from the averages noted in this study, and there is no encroachment upon existing water quality by substances which are inhibitory or toxic to algal turf communities, or development of serious deficiencies of substances critical to normal productivity. The values in figure 10 related to organic P are estimated form data provided by filtering the influent and effluent through a 10 micron filter (see table 6). The difference between total phosphorus before and after filtration is considered particulate phosphorus (recognizing it may be low because a 0.45 micron filter was not used). Of the filtered water, the dissolved organic phosphorus fraction is the difference between total and ortho phosphorus. (recognizing that some of the “dissolved “organic P may be polyphosphate). These estimates are offered for operational purposes, and we recognize they may not be scientifically defendable. They are reasonable estimates which offer some insight into the phosphorus dynamics at these low concentrations.



	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug (2009)
Influent	45	29	24	25	24	27	21	31	46	44
Effluent	34	16	17	17	16	22	12	22	25	31

Figure 7. Monthly mean inflow and outflow total phosphorus concentrations for STA-1W ATS™ Pilot with 10-micron solids recovery.

HydroMentia

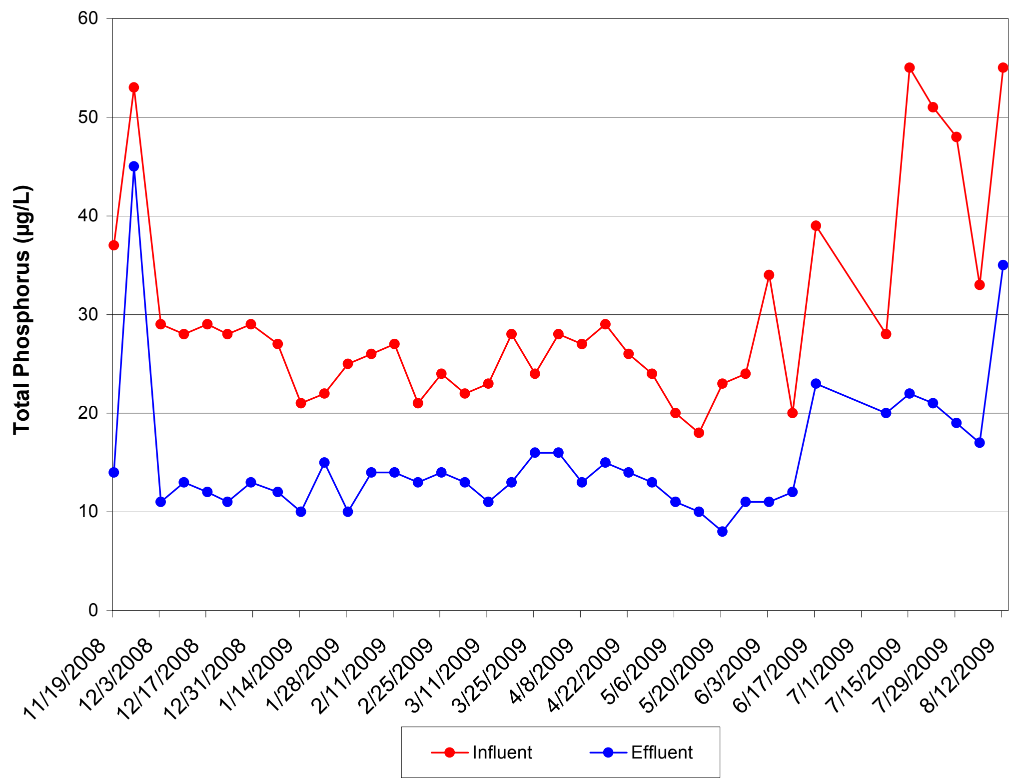


Figure 8. Weekly mean inflow and outflow total phosphorus concentrations for STA-1W ATS™ Pilot with 10-micron solids recovery.

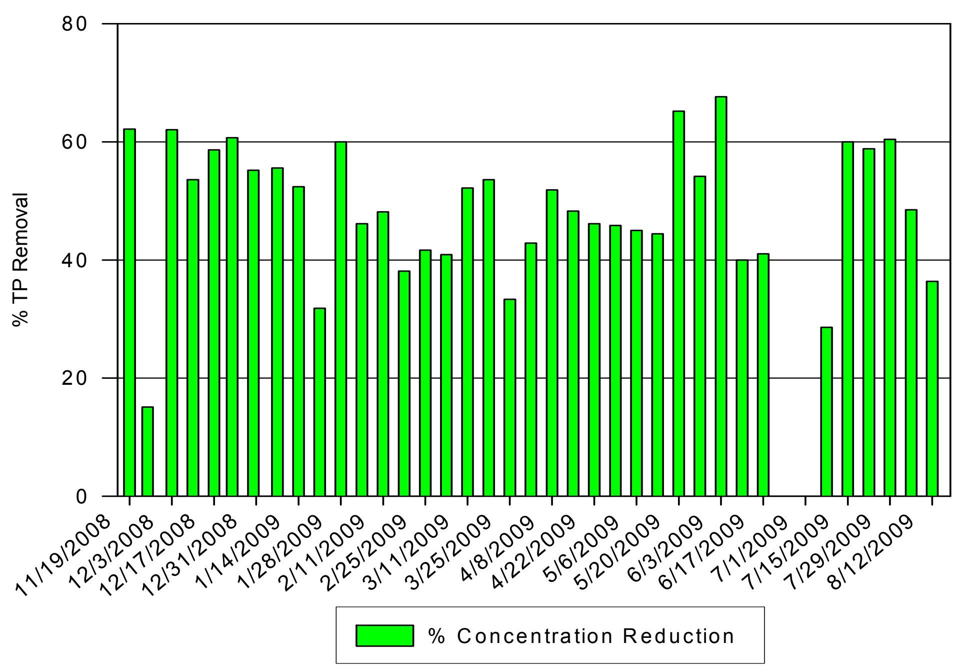


Figure 9. Weekly inflow and outflow total phosphorus percent reduction for STA-1W ATS™ Pilot with 10-micron solids recovery.

Table 4. STA-1W Total Phosphorus Water Quality Analysis for the period August 20, 2008 through August 12, 2009

	Inflow Total Phosphorus			Outflow Total Phosphorus			Percent Removal				
Sample Date	(a) Unfiltered Composite Sample (µg/L)	(b) Unfiltered Grab Sample (µg/L)	(c) Filtered Grab Sample (µg/L)	(d) Unfiltered Composite Sample (µg/L)	(e) Unfiltered Grab Sample (µg/L)	(f) Filtered Grab Sample (µg/L)	(a) - (d)	(b) - (e)	(a) - (f)	(b) - (c)	(e) - (f)
8/20/2008	27	14		24	12		?	14.3%			
8/27/2008	31	31		15	26		51.6%	16.1%			
9/3/2008	38	40		40	21		-5.3%	47.5%			
9/10/2008	45	48		26	26		42.2%	45.8%			
9/17/2008	62	76		89	73		-43.5%	3.9%			
9/24/2008	62	59		50	28		19.4%	52.5%			
10/1/2008	56	70		37	29		33.9%	58.6%			
10/8/2008	41	53		28	25		31.7%	52.8%			
10/15/2008	56	51		39	25		30.4%	51.0%			
10/22/2008	44	41		24	22		45.5%	46.3%			
10/29/2008	45	45		29	21		35.6%	45.3%			
11/5/2008	39	33		27	32		30.8%	3.0%			
11/12/2008	66	76		44	48		33.3%	36.8%			
11/19/2008	36	37	35	18	15	14	50.0%	59.5%	61.1%	5.4%	6.7%
11/25/2008	50	53	64	29	53	45	42.0%	0.0%	10.0%	-20.8%	15.1%
12/3/2008	35	29	27	18	15	11	48.6%	48.3%	68.6%	6.9%	26.7%
12/10/2008	28*	28	27	24*	24	13	14.3%	21.4%	53.6%	3.6%	45.8%
12/17/2008	29	29	28	22	14	12	24.1%	14.3%	58.6%	3.4%	14.3%
12/23/2008	28*	28	27	14*	14	11	50.0%	50.0%	60.7%	3.6%	21.4%
12/30/2008	28	29	29	12	13	13	57.1%	55.2%	53.6%	0.0%	0.0%
1/7/2009	27*	27	27	20*	20	12	25.9%	25.9%	55.6%	0.0%	40.0%
1/14/2009	25	21	21	14	12	10	44.0%	42.9%	60.0%	0.0%	16.7%
1/21/2009	26	22	21	14	23	15	46.2%	-4.5%	42.3%	4.5%	34.8%
1/28/2009	30	25	42	13	11	10	56.7%	56.0%	66.7%	-68.0%	9.1%
2/4/2009	27	26	24	18	17	14	33.3%	34.6%	48.1%	7.7%	17.6%
2/11/2009	30	27	28	16	14	14	46.7%	48.1%	53.3%	-3.7%	0.0%
2/18/2009	27	21	19	14	16	13	48.1%	23.8%	51.9%	9.5%	18.8%
2/25/2009	25	24	25	18	19	14	28.0%	20.8%	44.0%	-4.2%	26.3%
3/4/2009	27	22	21	26	17	13	3.7%	22.7%	51.9%	4.5%	23.5%
3/11/2009	26	23	22	17	15	11	34.6%	34.8%	57.7%	4.3%	26.7%

	Inflow Total Phosphorus			Outflow Total Phosphorus			Percent Removal				
Sample Date	(a) Unfiltered Composite Sample (µg/L)	(b) Unfiltered Grab Sample (µg/L)	(c) Filtered Grab Sample (µg/L)	(d) Unfiltered Composite Sample (µg/L)	(e) Unfiltered Grab Sample (µg/L)	(f) Filtered Grab Sample (µg/L)	(a) - (d)	(b) - (e)	(a) - (f)	(b) - (c)	(e) - (f)
3/18/2009	21	28	19	15	15	13	28.6%	46.4%	38.1%	32.1%	13.3%
3/25/2009	27	24	24	13	18	16	51.9%	25.0%	40.7%	0.0%	11.1%
4/1/2009	28*	28	27	38*	38	16	-35.7%	-35.7%	42.9%	3.6%	57.9%
4/8/2009	27*	27	25	15*	15	13	44.4%	44.4%	51.9%	7.4%	13.3%
4/15/2009	29*	29	27	18*	18	15	37.9%	37.9%	48.3%	6.9%	16.7%
4/22/2009	26*	26	27	21*	21	14	19.2%	19.2%	46.2%	-3.8%	33.3%
4/29/2009	27	24	21	21	16	13	22.2%	33.3%	51.9%	12.5%	18.8%
5/6/2009	20 (A)	20 (A)	19 (A)	15 (A)	12 (A)	11 (A)	23.3%	22.7%	46.7%	1.7%	13.5%
5/13/2009	20 (A)	18 (A)	17 (A)	17 (A)	12 (A)	10 (A)	13.6%	25.0%	47.5%	9.1%	11.4%
5/20/2009	19 (A)	23 (A)	22 (A)	11 (A)	11(A)	9 (A)	43.1%	48.0%	54.3%	4.3%	19.7%
5/27/2009	25	24	21	12	11	11	52.0%	53.8%	56.0%	12.5%	0.0%
6/3/2009	24	34	38	9.1	13	11	62.1%	61.8%	54.2%	-11.8%	15.4%
6/10/2009	30	20	18	17	12	12	43.3%	40.0%	60.0%	10.0%	0.0%
6/17/2009	31	39	38	23	40	23	25.8%	-2.6%	25.8%	2.6%	42.5%
6/24/2009	34*	34*	31	31	31	12	8.8%	8.8%	64.7%	8.8%	61.3%
7/1/2009	57			34			40.4%				
7/8/2009	39	28	29	18	25	20	53.9%	10.7%	48.7%	-3.6%	20.0%
7/15/2009	39	55	53	22	26	22	43.6%	49.1%	43.6%	3.6%	15.1%
7/22/2009	48	51	43	30	27	21	37.5%	47.1%	56.3%	15.7%	22.2%
7/29/2009	46	48	45	24	23	19	47.8%	52.1%	58.7%	6.3%	17.4%
8/5/2009	43	33	32	22	21	17	48.8%	36.4%	60.5%	3.0%	19.1%
8/12/2009	35	55	50	19	41	35	45.7%	25.5%	0.0%	9.1%	14.6%
Mean for Period Aug 20, 2008 through Aug 12, 2008	**35**	**34**	**NA**	**24**	**22**	**NA**	**33.3%**	**32.9**	**NA**	**NA**	**NA**
Mean for Period Nov 19, 2008 through Aug 12, 2008	**31**	**30**	**29**	**19**	**20**	**15**	**36.2%**	**34.1%**	**49.9%**	**2.3%**	**20.5%**

* Grab Sample
(A) Value reported is mean of 3 determinations

Table 5: Comparative Average Removals of Ortho and Organic Phosphorus of Unfiltered Samples

Quarter*	Influent Total Phosphorus (µgL)	Influent Ortho Phosphorus (µg/L)	Influent Organic Phosphorus (µg/L)	Effluent Total Phosphorus (µg/L)	Effluent Ortho Phosphorus (µg/L)	Effluent Organic Phosphorus (µg/L)	Percent Total Phosphorus Reduction**	Percent Ortho Phosphorus Reduction**	Percent Organic Phosphorus Reduction**
Q1	46	31	15	35	17	18	26%	45%	-20%
Q2	30	12	18	18	7	11	41%	42%	39%
Q3	25	10	15	19	8	11	24%	20%	27%
Q4	38	10	18	22	8	14	42%	20%	22%
Annual	**35**	**16**	**19**	**24**	**9**	**15**	**33%**	**44%**	**21%**

* Values as averages for designated period. All samples as unfiltered composite samples
** Percent removal based upon average concentrations.

Table 6: Comparative Average Phosphorus Removals of Filtered and Unfiltered Samples

Quarter	Unfiltered Influent TP µg/L	Filtered Influent TP µg/L	Percent Influent Particulate Phosphorus**	UnFiltered Effluent TP µg/L	Filtered Effluent TP µg/L	Percent Effluent Particulate Phosphorus**	Percent TP Reduction Unfiltered	Percent TP Reduction By Filtering Effluent	Percent Removal Improvement from Filtering Effluent
Q2*	33	32	3%	22	16	27%	33.3%	51.5%	18.2%
Q3	25	23	8%	19	14	26%	24.0%	44.0%	20.0%
Q4	37	35	5%	24	18	25%	35.1%	51.4%	16.3%
Total Period	**32**	**30**	**6%**	**22**	**16**	**27%**	**31.3%**	**50.0%**	**18.7%**

* Beginning November 18, 2008
** Particulate phosphorus in this case is that fraction removed by a 10 micron filter.

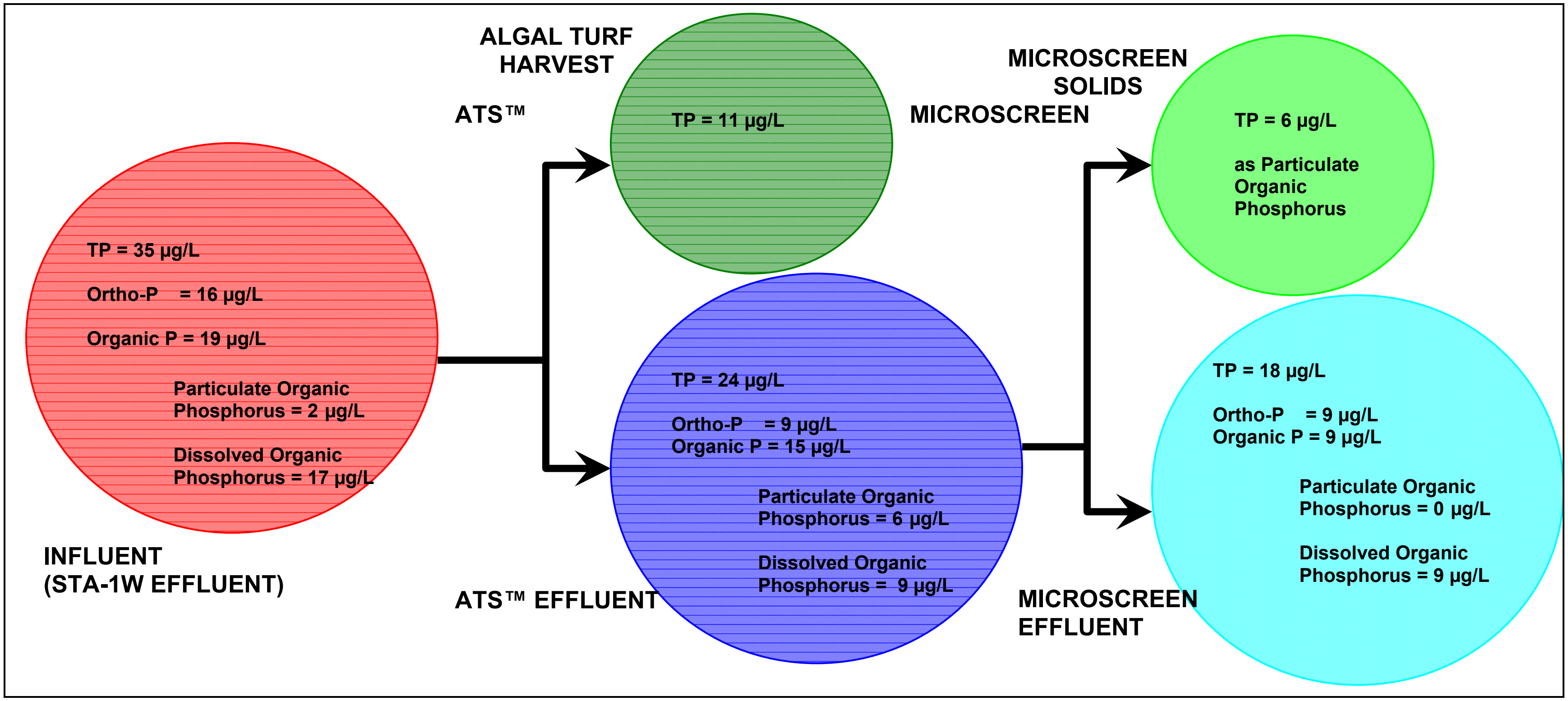


Figure 10: Generalized Phosphorus Dynamic through Microscreen assisted ATS™ Process. (Note – Generalized Values Do Not Reflect Actual Grab Sample Results)

* Beginning November 18, 2009

Phosphorus Accountability

In assessing the performance and behavior of the ATS™, it is helpful to independently calculate nutrient loads and removal rates using water quality data and harvest data. When these values track one another relatively closely, it adds confidence that both water quality and biomass sampling procedures reflect actual system dynamics. When evaluating these calculations however, it must be recognized that 1) the accuracy of harvest based calculations rely upon moisture and nutrient levels within a heterogeneous matrix (harvested algal turf), and accordingly may be considered the least accurate of the two calculation methods, and 2) there are other mechanisms for nutrient removal beside direct uptake and recovery of algal turf biomass, including potential incidental losses associated with emigration such as would be associated with larval emergence or external predation, or with immigration, such as an influx of visiting animal populations and atmospheric deposition. However, an estimated phosphorus balance has been calculated for this project.

Mass removal based upon harvested biomass is calculated as:

$P_{mh} = (sH_w)p$

Where P_{mh} = mass of phosphorus removed through harvesting
s = solids content as fraction of wet harvest
H_w = mass of wet harvest
(sH_w) = mass of dry harvest
p = tissue phosphorus content as fraction of dry harvest

Mass removal based upon water quality is calculated as

$P_{mw} = I_p Q_I – E_p Q_E$

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

Shown in Figure 11 is the comparison of phosphorus removals developed from water quality based and harvest based calculations. For both the cumulative and grab sample (unfiltered) water quality based calculations, the tracking of harvest based calculated removals appears reasonable, although the harvest based calculations are somewhat higher. As noted, harvest based calculations would be considered the least accurate, and in this case may be somewhat optimistic. When water quality from filtered (10 micron) samples is included, with other data included from 11/12/08 through 8/12/09, there is closer tracking of results, as noted in Figure 12.

The water quality based calculations and harvest based calculations can be used to estimate the areal removal rate of phosphorus (mass removal per unit are per unit time). Shown in Table 7 are quarterly TP areal removal rates based upon water quality calculations for unfiltered and filtered samples, and harvest based calculations.

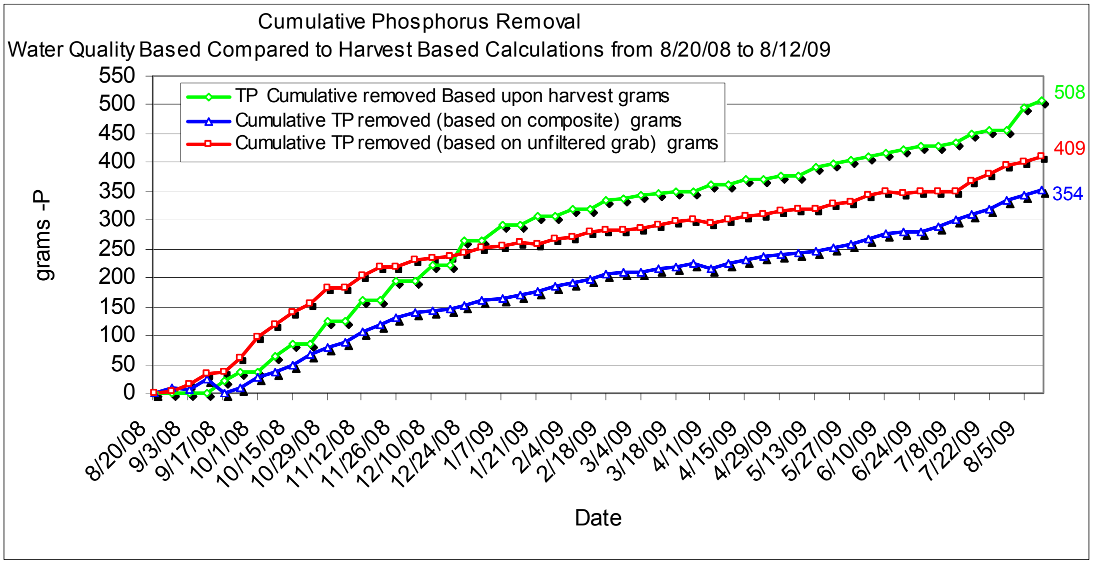


Figure 11: Phosphorus Accountability Water Quality Based as Compared to Harvest Based Calculations

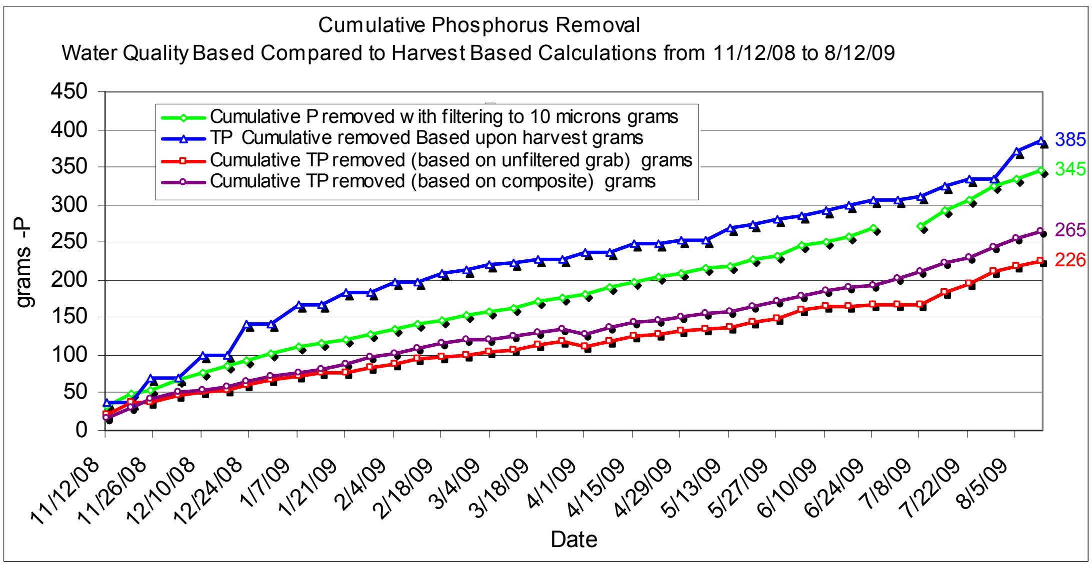


Figure 12: Phosphorus Accountability Water Quality Based as Compared to Harvest Based Calculations Including 10 micron Filtration Results.

Phosphorus Areal Removal Rates

The TP areal removal rates are higher as expected for calculations based upon filtered grab samples than those calculated for unfiltered composite samples, as they reflect the beneficial influence of 10 micron filtration. As with TP load removals, the TP areal removal rate is also higher for harvest based calculations when compared to those calculated for unfiltered composite samples. However harvest based calculated TP areal removal rates are similar to calculations based upon filtered grab samples.

Table 7: Total Phosphorus Areal Removal Rates for STA-1W ATS™ pilot

Quarter	TP Areal Removal Rate Based upon Unfiltered Composite Samples		TP Areal Removal Rate Based upon Filtered Grab Samples		TP Areal Removal Rate Based upon Harvest	
	mg/m^2-day	g/m^2-yr	mg/m^2-day	g/m^2-yr	mg/m^2-day	g/m^2-yr
Q1	10.9	4.0	-	-	15.7	5.7
Q2	9.0	3.3	13.0	4.8	15.8	5.8
Q3	3.9	1.4	7.5	2.7	7.0	2.6
Q4	10.0	3.6	13.5	4.9	11.5	4.2
Annual	**8.5**	**3.1**	**11.1**	**4.0**	**12.5**	**4.6**

The TP areal removal rate calculations are higher than what is experienced with STA systems operating in the Everglades region, suggestive that the ATS™, particularly when assisted by a microscreen, would require considerably less land to achieve the required TP removal.

It is not possible however to provide a direct comparison of areal removal rates between the STA-1W Algal Turf Scrubber® and Everglades STAs currently in operation as none of the current STAs are operating at inflow total phosphorus concentration of 35 µg/L or less.

As a means of providing a rough estimate of projected performance, provided in Table 8 are STA hydraulic loading rates and percent phosphorus removal for water years 2005 through 2009. In Table 9 are calculated theoretical STA phosphorus removal rates if it is assumed that system hydraulic loading rates are maintained at 3 or 4 cm/day, total phosphorus inflow concentration is 31 µg/L, and phosphorus removal rates are 70 – 80%.

Based on the assumptions provided, STA areal removal rates would be in the range of 0.24 – 0.36 g/m^2/yr. Under those assumptions, ATS™ (with filtration) areal removal rates would be 11 to 17 times greater than that achieved by the STAs. It is expected that data in the upcoming years will be available for STA systems operating under similar low inflow phosphorus concentrations as efforts are made to meet the 10 µg/L treatment objective.

Table 8: Stormwater Treatment Area (STA) operating conditions and treatment performance for Water Years 2005 though 2009.

Year	Annual Hydraulic Loading Rate of all STAs (cm/d)			Percent Phosphorus Removal
	Low	High	Mean	(%)
2009	0.28	2.88	1.58	80
2008	1.30	3.62	2.46	71
2007	1.74	4.39	3.07	68
2006	2.90	5.20	4.05	71
2005	3.70	5.10	4.40	69
		Mean	**3.11**	**72**

Table 9: Estimated Total Phosphorus Areal Removal Rates for Stormwater Treatment Area (STA) operating under theoretical assumed conditions.

Assumed Hydraulic Loading Rate (cm/day)	Assumed Inflow Phosphorus Concentration (ppb)	Calculated Phosphorus Loading Rate ($g/m^2/yr$)	Assumed Percent Removal (%)	Calculated Phosphorus Areal Removal Rate ($g/m^2/yr$)
3.0	31	0.34	70	0.24
3.0	31	0.34	80	0.27
4.0	31	0.45	70	0.32
4.0	31	0.45	80	0.36

NITROGEN DYNAMICS

While nitrogen is not a targeted nutrient within the listed TMDL for the Everglades, it is a key nutrient required for sustaining a viable algal turf community. As with many surface freshwaters in the South Florida region, most of the nitrogen associated with the STA-1W effluent is as total Kjeldahl nitrogen (TKN). TKN concentration is the sum of ammonia nitrogen and organic nitrogen concentrations. Review of historical data indicates that ammonia nitrogen levels within the STA-1W effluent averages 7.2% of the TKN[8], with organic nitrogen at 92.8% of the TKN. As the average influent TKN for the study period, based upon quarterly averages, was 2.37 mg/L, it is reasonable to estimate the average ammonia nitrogen at 0.17 mg/L.

A summary of total nitrogen results for weekly composite samples are noted in Table 8. Mean monthly nitrogen influent and effluent values are provided in Figure 13. Shown in Table 9 are the quarterly estimates for total nitrogen, nitrate-nitrite, TKN and ammonia nitrogen removal.

For the study period, based upon quarterly average influent and effluent composite sample concentrations, 5.1% of the influent nitrogen was removed. If it is assumed that all of the TKN removal is as ammonia nitrogen, then for the study period 64.7% of the ammonia nitrogen and 42.6% of the nitrate nitrogen was removed. There is little evidence that there was much enzymatic activity related to hydrolysis of organic nitrogen, and it appears that algal growth was supported by the existing concentrations of available nitrogen forms—nitrate, nitrite, and ammonia nitrogen.

While the percent nitrogen removal may appear low at 5.1% when compared to percent phosphorus removal (33.3%), it is commensurate with tissue levels of nitrogen and phosphorus. The ratio of total nitrogen removed to total phosphorus removed based upon influent and effluent concentrations (unfiltered), for the study period was 0.13 mg/L TN: 0.011 mg/L TP or 11.8. Based upon monthly tissue analyses (see Section 4), the average N:P ratio of harvested material based upon dry weight, was 1.21%:0.13% or 9.1. These two values are reasonably close, and provide indication that nutrient uptake is the primary mechanism associated with nutrient removal within the pilot system. The slightly lower value associated with the tissue N:P ratio suggests other sources of nitrogen beyond that available within the water, may have been accessed by the algal turf community---e.g. nitrogen fixation.

The accountability of nitrogen when tested with a comparison of mass removal based upon water quality calculations and harvest based calculations is not as close as with phosphorus. As noted in Figure 14, mass removal based upon harvest calculations is considerably higher than the water quality based calculations. This indicates that either nitrogen fixation was involved, or that there may have been some level of sample contamination or laboratory error. Because of the high N:P ratios within the STA-1W

[8] Stormwater Treatment Area one West (STA-1W) Algal Turf Scrubber® (ATS™) Basis of Design June, 2009. Prepared for South Florida Water Management District by HydroMentia, Inc.

influent, it would be thought conditions were not favorable for nitrogen fixation. Also, a review of the algal species differential noted in Appendix A shows *Cyanobacteria*, the group generally considered to be the primary nitrogen fixer, was estimated to compose only 2% of the total algal population. Nonetheless, it is difficult to reconcile the higher harvest based nitrogen removal without serious consideration of the possibility of nitrogen fixation.

As with mass removal, areal removal rates for nitrogen were higher for harvest based calculations, as noted in Table 10. The annual nitrogen areal removal rate was 24.9 g/m^2-yr based upon water quality calculations and 41.3 g/m^2-yr based upon harvest calculations.

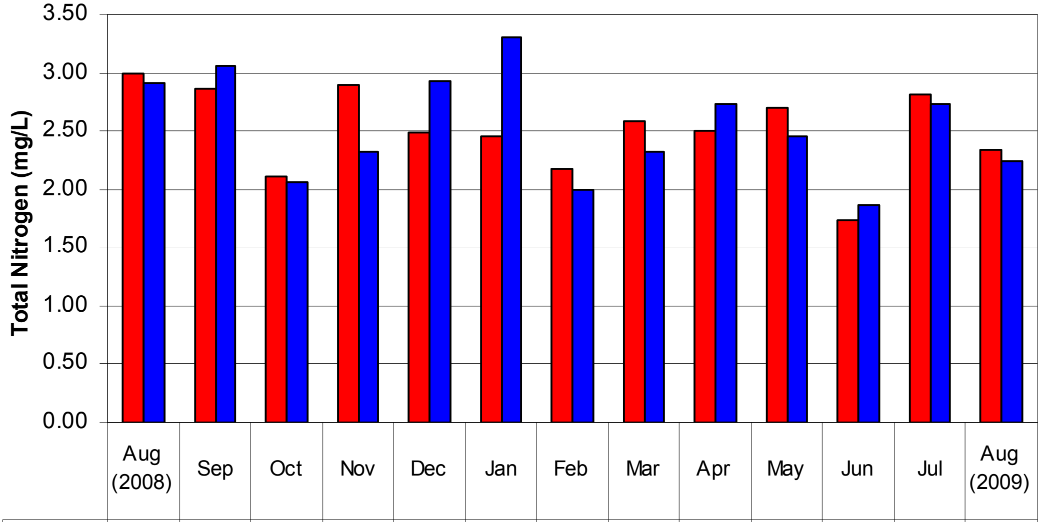
Throughout the duration of the pilot study, TN removal was inconsistent, showing high removal rates followed by periods of negative removal. As previously noted, this may relate to accuracy ranges associated with laboratory analysis; possible sample contamination; or atmospheric nitrogen fixation.

Table 8: Influent and Effluent Data for Weekly Composite Total Nitrogen for the Study Period

	TN			
Sample Date	**Influent (mg/L)**	**Effluent (mg/L)**	**% Reduction**	**Areal Removal Rate (mg/m^2-d)**
8/20/2008	2.13	1.92	10.09	34.03
8/27/2008	3.86	3.90	-1.04	-32.53
9/3/2008	2.97	2.72	8.59	205.13
9/10/2008	2.51	2.86	-13.94	-367.16
9/17/2008	2.91	3.53	-21.43	-658.57
9/24/2008	3.04	3.14	-3.29	-94.08
10/1/2008	2.99	2.75	8.03	227.83
10/8/2008	1.24	1.54	-24.19	-313.38
10/15/2008	2.55	2.44	4.35	112.19
10/22/2008	2.28	2.24	1.80	52.79
10/29/2008	1.45	1.31	9.72	152.22
11/5/2008	2.98	1.52	48.86	1458.27
11/12/2008	2.78	2.42	12.95	366.00
11/19/2008	2.90	2.92	-0.66	-7.85
11/25/2008	2.91	2.44	16.19	379.83
12/3/2008	2.38	3.04	-27.73	-619.34
12/10/2008	2.54	3.64**	-43.31	-872.43
12/17/2008	2.37	2.26	4.73	85.61
12/23/2008	2.26	2.84**	-25.80	-332.26
12/30/2008	2.84	2.82	0.70	20.33
1/7/2009	2.44	3.37**	-38.11	-690.59
1/14/2009	2.04	2.14	-4.90	-67.21
1/21/2009	2.82	2.68	4.96	104.45
1/28/2009	2.54	5.04***	-98.43	-1686.43
2/4/2009	2.80	2.15	23.21	450.58
2/11/2009	2.54	2.44	3.94	76.84
2/18/2009	1.14	1.14	0.00	4.08
2/25/2009	2.24	2.24	0.00	0.00
3/4/2009	2.68	2.26	15.67	278.90

	TN			
Sample Date	**Influent (mg/L)**	**Effluent (mg/L)**	**% Reduction**	**Areal Removal Rate (mg/m^2-d)**
3/11/2009	2.54	2.39	5.91	100.40
3/18/2009	2.56	2.27	11.33	192.74
3/25/2009	2.57	2.4	6.61	114.33
4/1/2009**	2.57	3.07	-19.46	-352.77
4/8/2009**	2.55	2.55	0.00	0.00
4/15/2009**	2.01	3.04	-51.24	-718.78
4/22/2009**	2.82	2.49	11.70	226.92
4/29/2009	2.54	2.53	0.39	6.79
5/6/2009	2.57	2.53	1.56	29.18
5/13/2009	3.17	2.599	18.01	442.58
5/20/2009	2.67	2.32	13.11	228.63
5/27/09	2.36	2.38	-0.64	-10.08
6/3/09	2.01	2.09	-4.13	-64.90
6/10/09	1.05	0.96	8.31	64.13
6/17/09	2.05	1.96	4.44	73.00
6/24/09	1.85	2.44	-32.11	-321.02
7/1/09	3.00	2.06	31.34	484.82
7/8/09	2.65	2.24	15.34	223.57
7/15/09	2.76	4.04	-46.59	-886.73
7/22/09	2.64	2.44	7.58	102.26
7/29/09	3.04	2.84	6.58	158.67
8/5/09	2.45	2.04	16.66	271.50
8/12/09	2.24	2.44	-8.93	-144.51
Mean Q1	**2.61**	**2.51**	**3.8**	**81.06**
Mean Q2	**2.43 (2.43)**	**2.77 (2.35)**	**-6.9 (3.3)**	**-242.04 (48.35)**
Mean Q3	**2.58 (2.63)**	**2.51 (2.37)**	**1.1 (9.9)**	**42.22 (173.34)**
Mean Q4	**2.37 (2.39)**	**2.33 (2.32)**	**-0.8 (2.9)**	**-4.11 (22.64)**
Annual Mean	**2.52**	**2.39**	**5.1**	**68.3**

*Value representative of grab sample
** Composite effluent sample site visibly contaminated
***Second laboratory analysis resulted in 2.3 mg/L TKN
(A) Value reported is mean of 3 determinations
( ) Values in parentheses indicate mean when potentially contaminated, and questionable laboratory result samples are removed from the dataset
Annual Mean based upon values in parenthesis as applicable



	Aug (2008)	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug (2009)
Influent	3.00	2.86	2.10	2.89	2.48	2.46	2.18	2.59	2.50	2.69	1.74	2.82	2.34
Effluent	2.91	3.06	2.06	2.33	2.92	3.31	1.99	2.33	2.74	2.46	1.86	2.72	2.24

Figure 13: Monthly mean inflow and outflow total nitrogen concentrations for STA-1W ATS™ Pilot.

Table 9: Nitrogen Removals on Quarterly Basis.

Quarter	Influent Total Nitrogen (mg/L)	Influent Total Kjeldahl Nitrogen (mg/L)	Influent Nitrate + Nitrite Nitrogen (mg/L)	Influent Estimated Ammonia Nitrogen (mg/L)*	Effluent Total Nitrogen (mg/L)	Effluent Total Kjeldahl Nitrogen (mg/L)	Effluent Nitrate + Nitrite Nitrogen (mg/L)	Effluent Estimated Ammonia Nitrogen (mg/L*)	Percent Total Nitrogen Reductio n **	Percent Total Kjeldahl Nitrogen Reduction **	Percent Nitrate+ Nitrite Reduction **	Percent Estimated Ammonia Nitrogen Reduction *	Percent of Nitrogen Removed associated with Nitrate + Nitrite Nitrogen	Percent of Influent Total Nitrogen as Nitrate + Nitrite Nitrogen	Percent of Effluent Total Nitrogen as Nitrate + Nitrite Nitrogen
Q1	2.61	2.44	0.17	0.18	2.51	2.39	0.12	0.11	3.8%	2.0%	29.4%	64.7%	50.0%	6.5%	4.8%
Q2	2.43	2.35	0.12	0.21	2.35	2.30	0.05	0.16	3.3%	2.1%	58.3%	76.1%	12.5%	4.9%	2.1%
Q3	2.63	2.37	0.18	0.18	2.37	2.29	0.09	0.10	9.9%	3.4%	50.0%	55.5%	65.4%	6.8%	3.8%
Q4	2.39	2.32	0.07	0.13	2.32	2.27	0.05	0.08	2.9%	2.2%	28.6%	61.5%	71.4%	2.9%	2.2%
Annual	**2.52**	**2.37**	**0.13**	**0.17**	**2.39**	**2.31**	**0.08**	**0.11**	**5.1%**	**2.4%**	**42.6%**	**64.7%**	**54.9%**	**5.4%**	**3.2%**

* Ammonia concentrations are estimated from percentage of historical TKN concentrations. All TKN removal is assumed to be as ammonia nitrogen
** Data set adjusted by omitting results associated with contaminated samples.

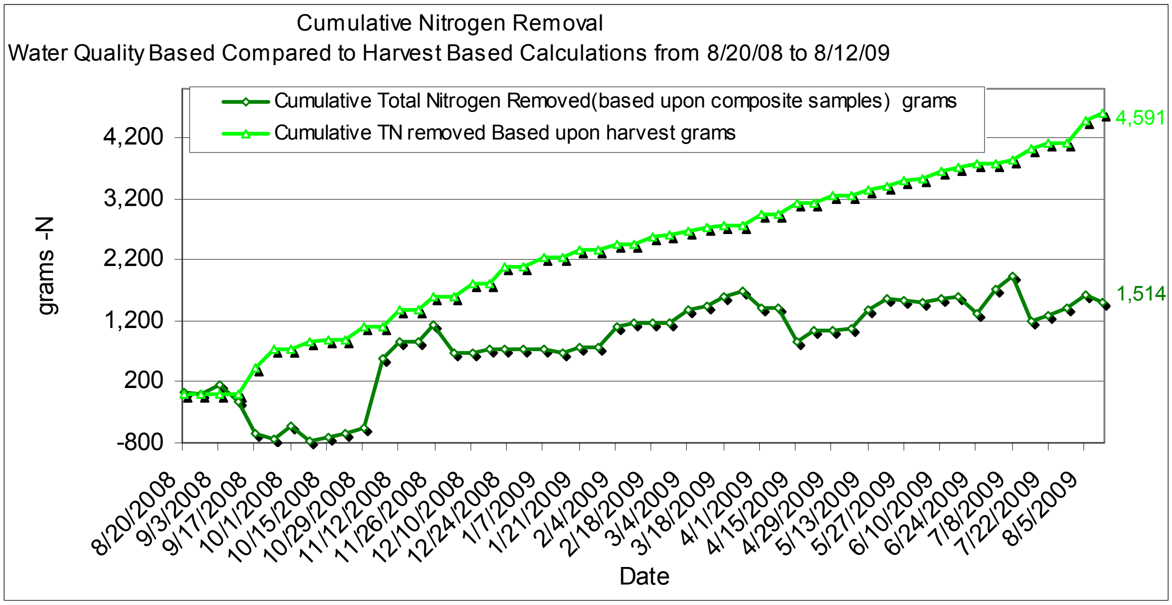


Figure 14: Nitrogen Accountability Water Quality Based as Compared to Harvest Based Calculations

Table 10: Total Nitrogen Areal Removal Rates

Quarter	TN Areal Removal Rate Based upon Composite Samples		TN Areal Removal Rate Based upon Harvest	
	mg/m^2-day	g/m^2-yr	mg/m^2-day	g/m^2-yr
Q1	81.1	29.6	135.5	49.5
Q2	48.4	17.6	106.7	39.0
Q3	173.3	63.3	88.3	32.2
Q4	22.6	8.3	121.9	44.5
Annual	**68.3**	**24.9**	**113.1**	**41.3**

OTHER WATER QUALITY PARAMETERS

Mean monthly influent and effluent concentrations of sampled parameters are shown in Table 11. Note that samples for total phosphorus (TP), total nitrogen (TN), total suspended solids (TSS), ortho-phosphate (O-PO_4) and nitrate plus nitrite (NO_2+NO_3) were collected weekly. Other parameters, such as metals and micronutrients were collected at monthly or quarterly intervals as described in Exhibit C of Contract #4600001289.

Table 11. Mean monthly influent and effluent nutrient concentrations for the STA-1W Algal Turf Scrubber® Pilot.

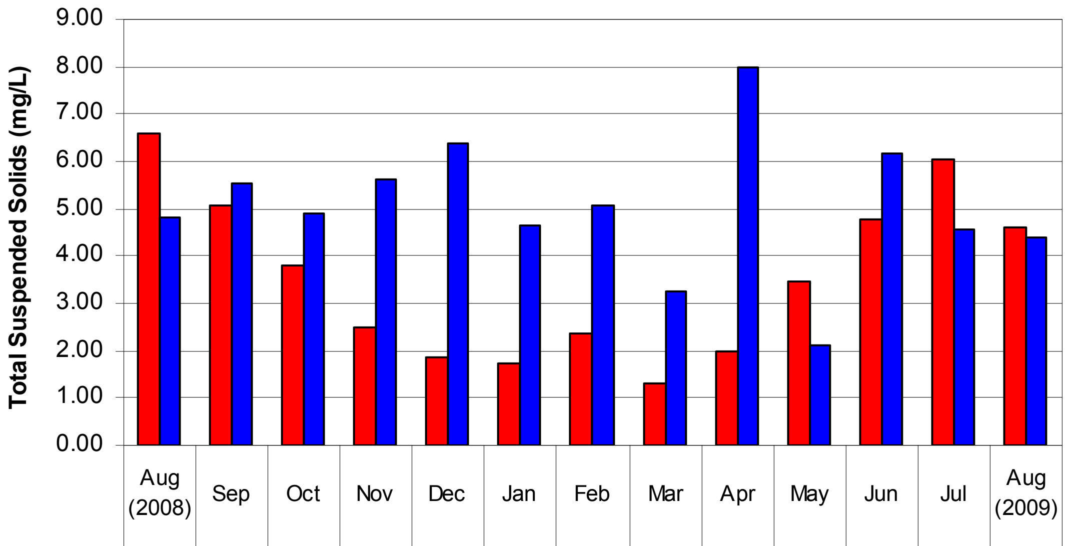
	Aug 2008		Sep 2008		Oct 2008		Nov 2008		Dec 2008		Jan 2009		Feb 2009	
	Influent	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
Phosphorus- Total (µg/L)	29	20	52	51	48	31	48	30	32	94	29	30	27	17
Orthophosphate (P) (µg/L)	9	6	46	21	34	17	21	14	19	9	5	5	10	8
Nitrogen-Total (mg/L)	3.00	2.91	2.86	3.06	2.10	2.06	2.89	2.33	2.48	2.92	2.46	3.31	2.18	1.99
Nitrogen- Total Kjeldahl (mg/L)	2.43	2.44	2.80	3.01	2.02	2.01	2.73	2.30	2.32	2.86	2.38	3.25	2.10	1.95
Nitrate-Nitrite (N) (mg/L)	0.57	0.47	0.06	0.05	0.08	0.04	0.17	0.03	0.16	0.06	0.09	0.06	0.08	0.04
Residues- Nonfilterable (TSS) (mg/L)	6.6	4.8	5.1	5.5	3.8	4.9	2.5	5.6	1.9	6.4	1.7	4.7	2.4	5.1
Residues- Volatile (mg/L)	5.3	3.9	3.8	3.6	3.0	3.5	2.0	4.5	1.9	4.1	1.8	2.7	2.1	4.1
Alkalinity (mg/L)			190				200		205		200		210	
Arsenic (µg/L)	U													
Boron (mg/L)	U													
Cadmium (µg/L)	U													
Calcium (µg/L)			63000				24000		57000		41000		47000	
Carbon- Total Organic (mg/L)			44				34		34.5		37		40	
Chromium (µg/L)	U													
Copper (µg/L)	U													
Iron (µg/L)			4300				U		55		470		U	
Lead (µg/L)	U													
Magnesium (µg/L)			26000				25000		25000		25000		29000	
Mercury (µg/L)	U													
Potassium (µg/L)	3400													
Selenium (mg/L)	U													
Zinc (µg/L)	U													

Table 11. Continued

	Mar 2009		Apr 2009*		May 2009		Jun 2009		Jul 2009		Aug 2009	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
Phosphorus- Total (µg/L)	25	17	28 (28)	59 (23)	20	14	43	24	43	24	39	21
Orthophosphate (P) (µg/L)	9	7	11	8	7	7	13	11	13	11	9	10
Nitrogen-Total (mg/L)	2.59	2.33	2.50	2.74	2.80	2.48	2.77	2.89	2.77	2.89	2.34	2.24
Nitrogen- Total Kjeldahl(mg/L)	2.40	2.25	2.30	2.64	2.63	2.37	2.73	2.85	2.73	2.85	2.3	2.2
Nitrate-Nitrite (N) (mg/L)	0.19	0.08	0.20	0.10	0.17	0.12	0.05	0.04	0.05	0.04	0.04	0.04
Residues- Nonfilterable (TSS) (mg/L)	U	3.25	U	7.98	2.4	2.1	6.05	4.58	6.05	4.58	4.6	4.4
Residues- Volatile (mg/L)	U	U	U	4.26	U	U	4.10	4.35	4.10	4.35	2.85	2.9
Alkalinity (mg/L)	260		260		220		230		230		230	
Arsenic (µg/L)												
Boron (mg/L)												
Cadmium (µg/L)												
Calcium (µg/L)	40		38		42		36		36		45	
Carbon- Total Organic (mg/L)	59000		41000		27000		64000		64000		17000	
Chromium (µg/L)												
Copper (µg/L)												
Iron (µg/L)	74		140		U		93		93		120	
Lead (µg/L)												
Magnesium (µg/L)	18000		19000		30000		25000		25000		21000	
Mercury (µg/L)												
Potassium (µg/L)												
Selenium (µg/L)												
Zinc (µg/L)												

Suspended Solids

For the 12 month study period, mean influent and effluent total suspended solids concentrations were 3.4 mg/L and 4.9 mg/L, respectively. During Q1, mean influent total suspended solids (TSS) concentration was 4.31 mg/L and mean effluent TSS was 4.48 mg/L, resulting in a mean weekly concentration increase of 0.39 mg/L for the first 13 weeks of operation (mean -39.2% removal on a weekly basis). During Q2, mean influent TSS was 2.00 mg/L and mean effluent TSS was 5.58 mg/L resulting in a mean weekly increase of 3.45 mg/L TSS. Mean influent TSS during Q3 was 1.90 mg/L while effluent TSS was 5.00 mg/L, resulting in a mean increase of 3.1 mg/L TSS. An elevated TSS result of 27 mg/L was obtained during the no-flow sampling event of 4/1/2009. During Q4 mean influent TSS was 5.37 mg/L and mean effluent TSS was 4.90 mg/L. It should be recognized that TSS values observed at the STA-1W ATS™ pilot are relatively low; often reported as "between the laboratory MDL and the laboratory PQL". Monthly influent and effluent TSS concentrations are shown in Figure 15.



	Aug (2008)	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug (2009)
Influent	6.60	5.05	3.80	2.48	1.88	1.73	2.38	1.30	1.98	3.45	4.78	6.05	4.60
Effluent	4.80	5.53	4.90	5.60	6.38	4.65	5.05	3.25	7.98	2.10	6.18	4.58	4.40

Figure 15. Mean monthly influent and effluent total suspended solids concentration.

This trend is most likely due to sloughing of algal turf between harvests. In general, lower productivity rates are observed during the colder winter and spring months, thus harvest frequency was predicted to be adequate for every two weeks for the first six months of operation. Adjustments to harvest frequency were made throughout the study period based on observations by field staff. As noted previously, filtration of effluent samples indicates that effluent solids could be reduced with a microscreen, which would also reduce associated nutrients.

pH, Dissolved Oxygen (DO), Water Temperature and Conductivity

Typical changes within the effluent were noticed throughout Q1-Q4, with a rise in daytime pH, DO and water temperature relative to influent values. This is attributable to the influence of photosynthesis, and the associated consumption of bicarbonate and carbonate alkalinity and the generation of oxygen. Water temperature changes across the floway relate to the increased surface area for heat exchange facilitated by the floway. Weekly ambient water quality conditions as measured using a hand-held multi-parameter unit (YSI) are shown in Table 12. Mean monthly values are provided in Figure 16. All samples were taken during daylight hours, when photosynthetic activity was high.

Table 12. Influent and effluent daytime conductivity, water temperature, pH and DO at the STA-1W ATS™ Pilot via hand-held multi-parameter unit (YSI).

	Conductivity (µS/cm)		Temp (ºC)		pH		DO (mg/L)		Alkalinity (mg/L)	
Sample Date	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
8/20/2008	615	654	25.8	30.46	7.53	8.61	5.31	5.31	180	180
8/27/2008	623	580	29.44	33.5	7.64	8.69	3.47	8.41	160	160
9/3/2008	964	1052	28.16	33.5	7.46	8.07	4.09	9.05	160	160
9/10/2008	1025	1023	27.12	28.74	6.97	7.44	3.12	10.81	160	160
9/17/2008	1072	1093	29.43	32.28	7.65	8.16	2.75	8.9	160	160
9/24/2008	1026	984	28.34	27.65	7.61	8.31	2.66	2.59	160	160
10/1/2008	1050	1032	29.2	31.68	7.25	8.4	2.11	12.82	140	140
10/8/2008	893	917	27.02	30.69	7.52	8.66	3.43	10.75	140	140
10/15/2008	850	790	26.91	30.13	8.37	9.2	4.31	13.71	140	140
10/22/2008	874	858	26.02	27.83	7.38	8.57	6.12	15.7	160	160
10/29/2008	860	825	20.57	18.07	7.09	8.45	6.49	16.24	160	160
11/6/2008	873	818	21.77	22.4	7.94	8.62	5.77	15.62	160	160
11/12/2008	837	846	22.45	25.14	7.22	8.42	6.9	14.67	160	160
11/19/2008	784	734	19.82	20.95	7.52	8.15	8.14	19.56	160	160
11/25/2008	663	579	18.45	21.66	7.65	8.09	7.81	19.63	180	180
12/3/2008	801	747	18.22	19.32	7.8	8.69	8.57	20.24	160	160
12/10/2008	804	746	19.83	24.86	7.43	8.58	7.48	16.6	160	160
12/17/2008	751	765	20.99	24.26	7.81	9.2	8.69	16.12	180	180
12/23/2008	825	775	19.98	20.64	7.54	8.42	8.92	17.38	180	180
12/30/2008	830	759	22.34	24.52	7.43	8.68	7.56	18.08	180	180
1/7/2009	831	798	21.92	22.36	7.68	8.33	4.8	10.8	180	180
1/14/2009	767	787	20.26	25.43	7.66	8.6	6.86	12.99	180	180
1/21/2009	663	579	13.15	8.66	7.65	8.09	7.81	19.63	180	180
1/28/2009	912	948	20.03	25.16	7.65	8.14	8.22	14.25	240	240
2/4/2009	851	773	17.14	13.76	7.86	8.4	10.33	16.11	240	240
2/11/2009	875	934	17.65	23.37	7.01	7.78	9.16	16.25	240	240
2/18/2009	917	910	19.17	21	7.66	8.12	8.75	15.7	240	240
2/25/2009	954	938	19.41	20.89	7.42	8.47	7.35	13.55	200	200
3/4/2009	914	876	17.22	17.29	7.68	8.72	9.87	15.23	200	200
3/11/2009	1011	999	21.78	22.06	7.67	8.61	7.75	12.63	200	200

3/18/2009	1053	984	22.8	20.5	7.4	8.63	6.4	1.88	200	200
3/25/2009	1015	989	21.53	21.42	7.48	8.52	6.51	10.81	200	200
4/1/2009	1094	1089	25.26	27.99	7.35	8.67	5.89	9.6	160	160
4/8/2009	1029	975	21.65	20.68	7.17	8.25	6.76	11.89	200	200
4/15/2009	1111	1084	24.23	26.11	7.65	8.47	5.7	11.36	240	240
4/22/2009	1108	1098	24.14	26	7.67	8.42	5.56	10.93	200	200
4/29/2009	1146	1105	25.28	25.65	7.31	8.29	6.47	10.9	200	200
5/6/2009	1219	1288	27.32	30.19	7.02	8.1	5.66	10.25	200	200
5/13/2009	1186	1250	27.99	28.49	7.63	8.38	4.7	11.16	200	200
5/20/2009	1192	1134	26.04	25.83	7.38	8.01	5.2	11.13	180	180
5/27/2009	819	852	26.45	31.43	7.64	8.25	3.75	9.28	180	180
6/3/2009	898	883	27.75	30.59	7.61	8.18	4.57	10.76	200	200
6/10/2009	955	1000	28.58	33.36	7.56	8.24	4.6	9.71	200	200
6/17/2009	808	768	31.32	31.39	7.84	8.22	8.47	9.79	200	200
6/24/2009		747		31.61		8.02		12.66		200
6/28/2009	794		28.93		7.56		4.99		200	
7/8/2009	1148	1153	30.4	33.03	7.64	8.01	5.53	11.4	200	200
7/15/2009	1143	1180	30.65	34.99	7.8	8.43	5.19	10.68	200	200
7/22/2009	1044	1104	29.25	32.7	7.6	8.29	4.86	11.49	200	200
7/29/2009	1071	1044	30.04	31.84	7.22	8.49	4.18	13.55	200	200
8/5/2009	1071	1044	30.04	31.84	7.22	8.49	4.18	13.55	200	200
8/12/2009	1131	1146	30.33	33.17	7.67	8.32	3.87	12.37	200	200
Q1 Mean	**859**	**842**	**25.73**	**28.01**	**7.56**	**8.45**	**4.67**	**11.81**	**159**	**159**
Q2 Mean	**816**	**791**	**19.24**	**21.51**	**7.60**	**8.37**	**8.08**	**16.25**	**199**	**199**
Q3 Mean	**1079**	**1062**	**23.43**	**24.08**	**7.45**	**8.42**	**6.45**	**10.87**	**198**	**198**
Q4 Mean	**1019**	**1021**	**29.29**	**32.11**	**7.58**	**8.26**	**4.97**	**11.29**	**197**	**197**
Annual Mean	**936**	**922**	**24.31**	**26.21**	**7.53**	**8.38**	**6.03**	**12.64**	**186**	**186**

Monthly mean conductivity, temperature, pH, DO and alkalinity are shown in Figure 16 (a through e).

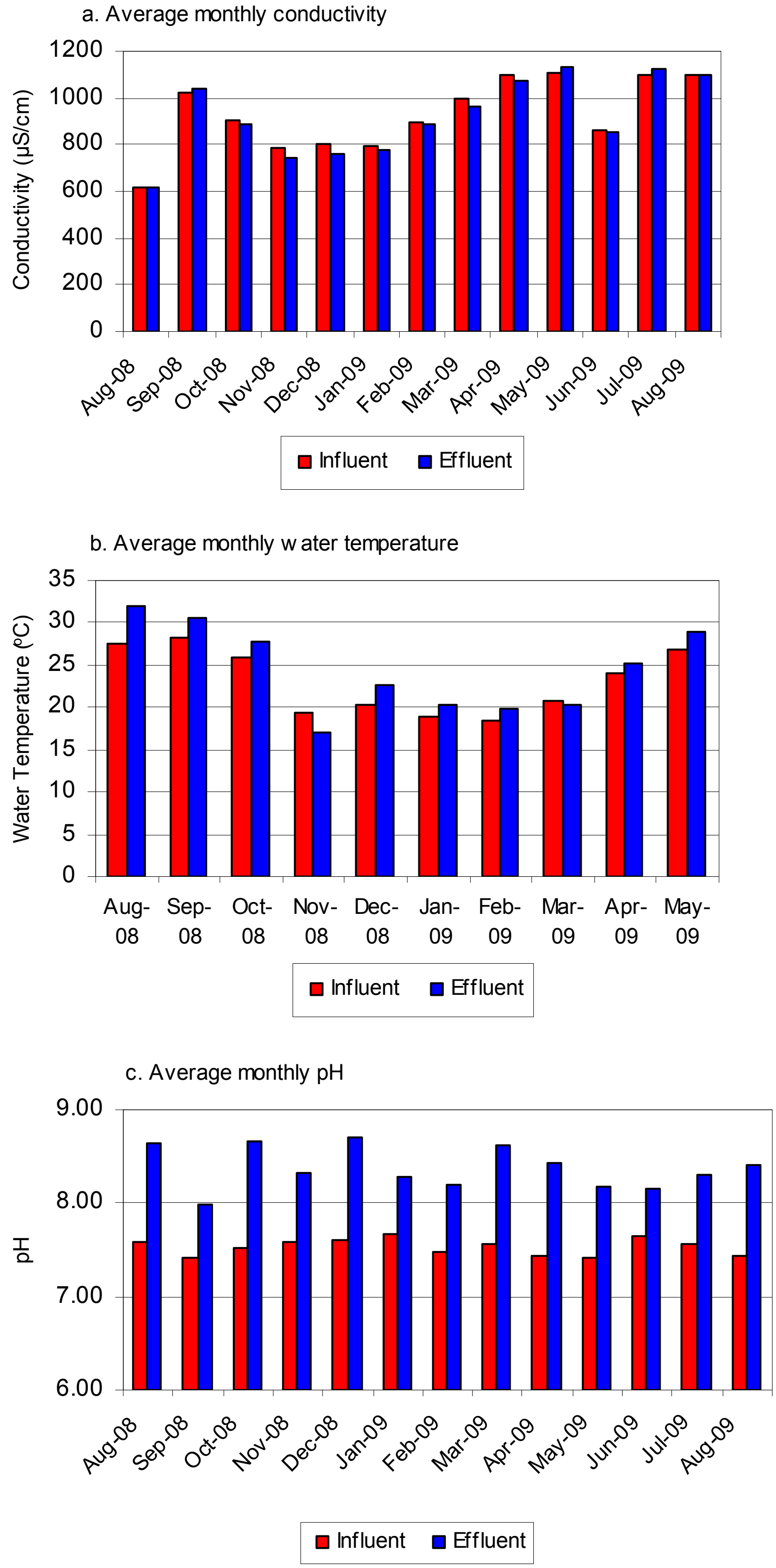
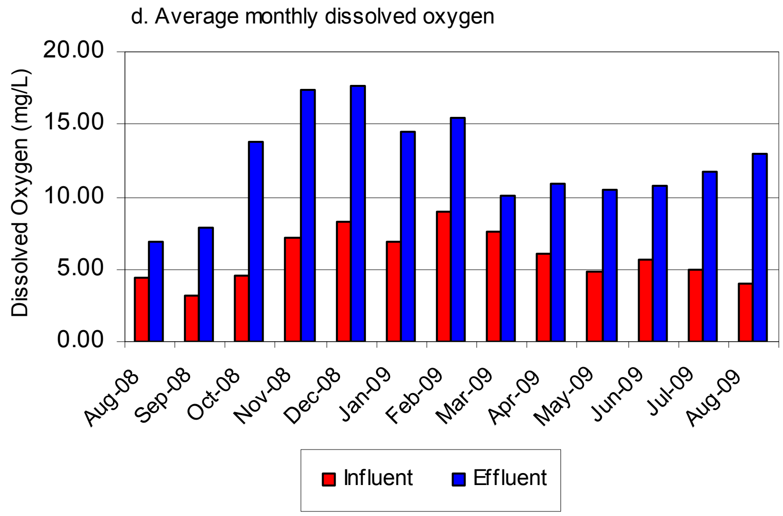


Figure 16. Mean monthly ambient water quality parameters at the STA-1W ATS™ Pilot (a through e) based upon daytime sampling.



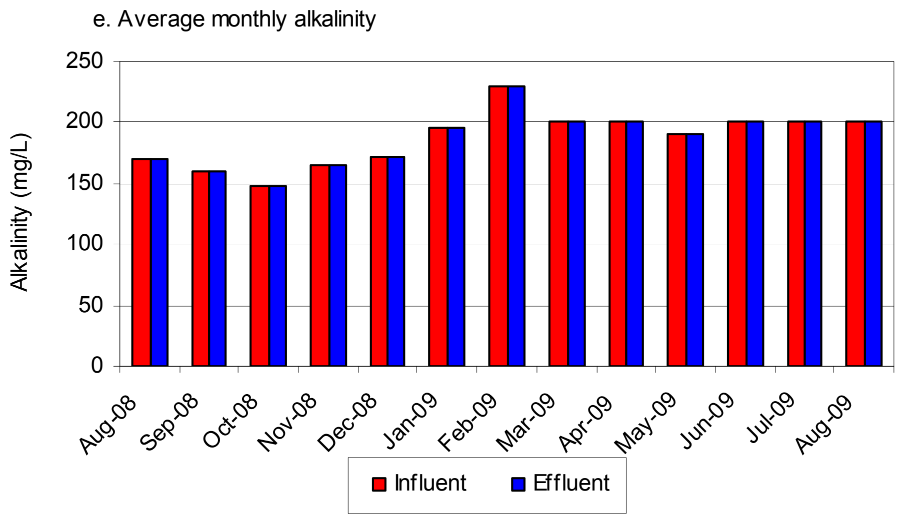


Figure 16 (Cont). Mean monthly ambient water quality parameters at the STA-1W ATS™ Pilot (a through e) based upon daytime sampling.

Water temperature is an important environmental factor in terms of influence upon algal turf productivity. Generally, the floway, with its shallow laminar flow, permits flows to become closely equilibrated with air temperature. Table 13 includes a summary of monthly mean water and air temperature at the STA-1W Algal Turf Scrubber® Pilot with respect to historical trends.

Table 13: Temperature trends compared to historical conditions at STA-1W for Q1-Q4.

Month	Historical Mean Influent Water Temperature (ºC)	Actual Mean Influent Water Temperature (ºC)	Historical Mean Air Temperature (ºC)	Actual Mean Air Temperature (ºC)
August_2008	28.74	31.98	27.15	27.48
September	27.88	30.54	26.63	26.63
October	24.94	27.68	24.68	23.64
November	21.32	19.75	20.55	18.78
December	18.63	20.72	19.10	19.27
January	16.12	18.84	17.51	16.78
February	19.48	18.34	19.17	17.08
March	21.74	20.83	21.07	18.74
April	23.57	24.11	22.05	21.04
May	26.34	26.95	24.45	24.17
June	28.00	29.15	22.78	23.16
July	28.13	30.09	23.62	23.66
August_2009	28.69	31.24	27.14	27.54
Mean Q1	**25.72**	**28.07**	**24.68**	**24.23**
Mean Q2	**18.08**	**18.76**	**18.59**	**17.92**
Mean Q3	**23.88**	**23.43**	**22.52**	**21.31**
Mean Q4	**28.27**	**30.16**	**24.51**	**24.79**

SECTION 4. ASSESSMENT OF BIOMASS HARVESTING AND PROCESSING

The STA-1W Pilot ATS™ was initiated Aug. 13, 2008 with the first water quality samples collected Aug. 20, 2008. Filamentous green algae were observed on the first 300 ft of floway, with diatom presence from 300 to 900 ft beginning with the first sample event. During the week of September 3, an influent line became clogged, which reduced the flow to the system. This resulted in an estimated loss of approximately 60% of the algae/diatom community after 300ft. A recovery of algal/diatom biomass was observed the following week.

At the beginning of Quarter 2, the majority of the algal turf was composed of green and brown filamentous algae, with a notable presence of amphipods, insect larvae and aquatic insects along the floway. A community shift toward more green algae after 300 ft was observed on 1/7/09. At the end of the quarter (2/18/09), observation from 0-300 ft identified approximately 60% coverage of brown filamentous (largely filamentous diatoms) algae and 40% green filamentous algae. From 300 ft to 600 ft algal composition was approximately 60% brown filamentous algae, 25% green filamentous algae, and 15% of an un-identified white/brown material which appeared calcareous. Algal samples were collected and green algae were identified as *Cladophora sp*., *Spyrogira sp.* and *Rizhoclonium* sp. After 600 ft, *Spyrogira sp*. was the only green algae noted. Throughout the end of Q3 and beginning of Q4, species of blue green algae were observed in the first 200 ft. The remainder of the floway showed a white/brown calcareous substance with filamentous algae attached. As noted previously, a dry out occurred on 7/1/09, resulting in desiccation of the system. The algae recovered quickly, and showed a shift toward more filamentous algae in the first 600 ft for the duration of the quarter.

For the STA-1W ATS™ Pilot, biomass was harvested and weighed in 300 ft segments in order to examine potential differences in productivity over the length of the floway. Samples are collected at each harvest, dried and composited monthly for analysis. Wet biomass weight for each harvest event is presented in Table 14.

Table 14. Wet harvest amounts at 300ft intervals for the STA-1W Algal Turf Scrubber® Pilot Project

Operational Date	0-300' (lbs)	300-600' (lbs)	600-900' (lbs)	900-1200' (lbs)	Total Wet Harvest (lbs)
9/17/2008	19.6	37.0	81.7	158.8	297.0
10/8/2008	84.2	83.5	76.7	44.2	288.7
10/15/2008	121.5	61.8	59.5	44.5	287.3
10/29/2008	143.0	137.0	150.0	122.0	552.0
11/6/2008	162.0	114.0	167.0	208.0	651.0
11/25/2008	115.0	113.0	116.0	96.0	440.0
12/10/2008	98.0	130.0	110.0	71.0	409.0
9/24/2008	36.6	72.8	92.5	110.8	312.7
11/12/2008	162.0	114.0	167.0	208.0	651.0
12/23/2008	147.0	184.0	125.0	109.0	565.0
1/7/2009	134.0	187.0	120.0	109.0	550.0
1/21/2009	107.0	83.0	71.0	56.0	317.0
2/4/2009	124.0	90.0	73.0	55.0	342.0
2/18/2009	111.0	99.0	70.0	61.0	341.0
2/25/2009	200.0	0.0	0.0	0.0	200.0
3/4/2009	79.9	67.0	70.7	46.3	263.9
3/11/2009	66.8	28.5	0.0	0.0	95.3

Operational Date	0-300' (lbs)	300-600' (lbs)	600-900' (lbs)	900-1200' (lbs)	Total Wet Harvest (lbs)
3/18/2009	58.3	39.6	47.1	44.1	189.1
4/1/2009	170.7	94.8	49.8	61.6	376.9
4/15/2009	196.5	148.7	49.2	32.4	426.8
4/22/2009	112.6	88.9	0.0	0.0	201.5
4/29/2009	84.7	51.5	69.0	73.3	278.5
5/13/2009	175.9	89.8	31.8	41.5	339.0
5/20/2009	94.3	34.6	0.0	0.0	128.9
5/27/2009	86.3	31.6	31.9	30.3	180.1
6/3/2009	113.4	31.8	0.0	0.0	145.2
6/10/2009	109.2	31.0	83.7	56.1	280.0
6/17/2009	153.8	42.2	0.0	0.0	196.0
6/24/2009	94.7	34.5	81.0	52.7	262.9
7/8/2009	42.8	69.1	0.0	0.0	111.9
7/15/2009	110.0	71.0	71.0	69.0	321.0
7/22/2009	102.0	45.0	0.0	0.0	147.0
8/5/2009	149.0	124.0	176.0	134.0	583.0
8/12/2009	90.0	64.0	23.0	30.0	207.0
Q1 Total	**728.9**	**620.0**	**794.3**	**896.4**	**3,039.6**
Q2 Total	**836.0**	**886.0**	**685.0**	**557.0**	**2,964.0**
Q3 Total	**1,239.7**	**643.4**	**317.6**	**299.2**	**2,499.9**
Q4 Total	**1,051.2**	**544.2**	**466.6**	**372.1**	**2,434.1**
Annual Total	**3,855.8**	**2,693.6**	**2,263.5**	**2,124.7**	**10,937.6**

Determination of total phosphorus removal through bio-solids is based upon percent of solids in harvested material and the tissue nutrient levels. At the STA-1W ATS™ pilot, harvested material averaged 6.0% solids for the first quarter. Mean solids for Q2 increased to 7.6%; to 8.0% during Q3 and to 9.4% during Q4. Note that % solids increased over the length of the floway during all four quarters however, the amount of material harvested generally decreased from 0-300 ft to 900-1200 ft during Quarters 2-4 as shown in Table 14.

Table 14. Algal % solids based on distance from influent at 300 ft intervals.

Operational Date	0-300' (% Solids)	300-600' (% Solids)	600-900' (% Solids)	900-1200' (% Solids)	Mean % Solids for Harvest
9/17/2008	3.5	7.6	8.1	7.4	6.6
10/8/2008	5.8	6.1	6.8	7.4	6.5
10/15/2008	3.9	5.5	6.0	7.7	5.8
10/29/2008	4.7	5.1	5.3	6.3	5.4
11/6/2008	5.6	5.1	5.0	7.3	5.8
12/23/2008	6.9	6.8	8.1	8.7	7.6
1/7/2009	6.1	6.4	8.6	8.5	7.4
1/21/2009	5.9	5.8	7.9	7.7	6.8
2/4/2009	6.6	7.3	8.4	9.2	7.9
2/18/2009	6.4	7.4	9.3	10.0	8.3
2/25/2009	6.5	No Harvest	No Harvest	No Harvest	6.5

3/4/2009	6.9	9.0	11.7	11.1	9.7
3/11/2009	7.5	7.8	0.0	0.0	3.8
3/18/2009	6.2	6.6	9.5	9.8	8.0
4/1/2009	6.4	9.8	11.7	10.6	9.6
4/15/2009	7.5	8.2	11.5	14.0	10.3
4/22/2009	6.6	6.2	No Harvest	No Harvest	6.4
5/6/2009	7.6	7.5	11.6	12.0	9.7
5/13/2009	7.6	6.9	7.7	10.6	8.2
5/20/2009	7.6	8.4	No Harvest	No Harvest	8.0
5/27/2009	8.6	9.8	9.1	12.8	10.1
6/3/2009	7.0	8.1	No Harvest	No Harvest	7.6
6/10/2009	6.9	9.7	9.4	12.1	9.5
6/17/2009	7.7	8.4	No Harvest	No Harvest	8.1
6/24/2009	7.3	8.6	7.6	9.4	8.2
7/8/2009	8.6	9.6	No Harvest	No Harvest	9.1
7/15/2009	8.1	9.9	10.7	10.1	9.7
7/22/2009	8.8	9.2	No Harvest	No Harvest	9.0
8/5/2009	9.2	9.5	11.7	13.1	10.9
8/12/2009	6.5	6.1	9.8	9.4	8.0
Q1 Mean % Solids	**4.7**	**5.8**	**6.2**	**7.2**	**6.0**
Q2 Mean % Solids	**6.4**	**6.7**	**8.5**	**8.8**	**7.6**
Q3 Mean % Solids	**6.9**	**7.9**	**9.3**	**9.6**	**8.0**
Q4 Mean % Solids	**7.9**	**8.9**	**9.7**	**11.2**	**9.4**
Annual Mean	**6.8**	**7.3**	**8.2**	**9.1**	**7.7**

Nutrient tissue content was determined monthly for each harvest segment. Mean algal total phosphorus content for Q1 was 0.246%, and mean algal total nitrogen content for Q1 was 1.55%. Mean algal total phosphorus for Q2 was 0.157%, and mean total nitrogen content was 1.13%. Mean algal total phosphorus for Q3 was 0.065%, and mean total nitrogen content was 0.84%. Mean algal total phosphorus for Q4 was 0.107%, and mean total nitrogen content was 1.30%.These and other nutrient parameters for harvested algae are shown in Table 15. As shown in Figure 17, algal total phosphorus content (as % weight) decreased over the length of the floway in all twelve months, and was below analytical detection limits after 600 ft for February through May 2009. This trend is likely associated with lower total phosphorus influent water concentrations during Q2 and Q3.

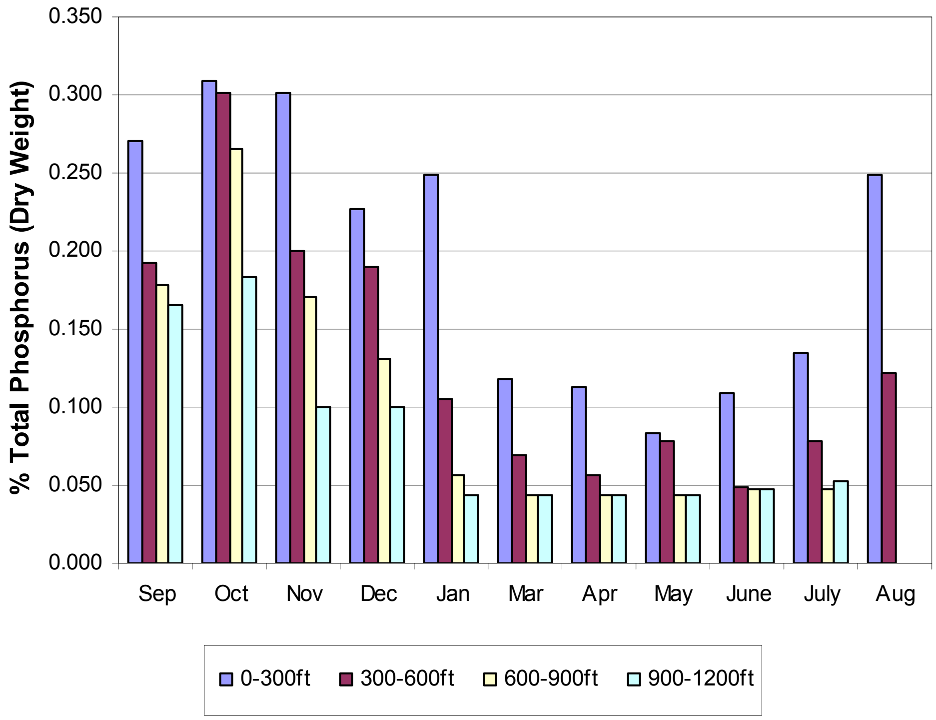


Figure 17. Tissue phosphorus content (%) from monthly composited samples at 0-300 ft, 300-600 ft, 600-900 ft, and 900-1,200 ft intervals from the influent surge box.

Table 15. Q1-Q4 Algal nutrient content for the STA-1W Algal Turf Scrubber® Pilot

Parameter	Month	300 ft	600 ft	900 ft	1200 ft	Mean
Total Phosphorus (%)	Sep	0.270	0.192	0.179	0.166	0.202
	Oct	0.310	0.301	0.266	0.183	0.265
	Nov	0.301	0.201	0.170	0.100	0.193
	Dec	0.227	0.190	0.131	0.100	0.171
	Jan	0.249	0.105	0.057	U	0.113
	Mar	0.118	0.070	U	U	0.069
	Apr	0.113	0.057	U	U	0.064
	May	0.083	0.078	U	U	0.062
	June	0.109	0.049	0.047	0.048	0.058
	July	0.135	0.078	0.048	0.052	0.078
	Aug	0.249	0.122	No Harvest	No Harvest	0.185
Total Nitrogen (%)	Sep	1.76	1.41	1.46	1.45	1.52
	Oct	1.92	1.72	1.66	1.34	1.66
	Nov	1.79	1.54	1.47	1.17	1.49
	Dec	1.53	1.40	1.19	0.94	1.30
	Jan	1.56	0.86	0.62	0.55	0.90
	Mar	1.14	0.91	0.48	0.49	0.76
	Apr	1.54	1.06	0.90	0.67	1.04
	May	0.92	0.71	0.85	0.40	0.72
	June	1.58	1.25	1.03	0.82	1.17
	July	1.56	1.21	0.95	0.98	1.18
	Aug	1.83	1.29			1.56
Ammoniacal Nitrogen (%)	Nov	0.04	0.02	0.01	0.01	0.02
	Dec	0.16	0.01	0.07	0.01	0.10
	Jan	U	U	U	U	U
	Mar	0.01	U	U	U	U
	Apr	0.00	U	U	U	U
	May	0.00	U	U	U	U
	June	0.00	U	U	U	U
	July	0.01	0.01	U	0.01	0.01
	Aug	0.01	U			U
Boron (ppm)	Sep	U	U	U	U	U
	Oct	U	U	U	U	U
Calcium (%)	Sep	13.13	19.61	19.07	20.47	18.07
	Oct	11.46	13.11	112.00	19.45	39.01
	Nov	10.02	15.95	16.12	19.44	15.38
	Dec	15.36	17.74	18.15	22.88	17.94
	Jan	15.58	19.28	24.28	29.33	22.12
	Mar	14.29	17.26	22.43	24.86	19.71
	Apr	14.05	17.71	22.79	24.75	19.83
	May	17.79	17.87	23.80	28.57	22.01

Parameter	Month	300 ft	600 ft	900 ft	1200 ft	Mean
	June	17.98	22.66	26.04	28.98	23.92
	July	20.64	26.06	28.28	27.81	25.70
	Aug	18.36	20.18			19.27
Chloride (%)	Nov	0.19	0.18	0.22	0.16	0.19
	Dec	0.15	0.16	0.15	0.14	0.15
	Jan	0.10	0.17	0.21	0.35	0.21
	Mar	0.29	0.15	0.11	0.18	0.18
	Apr	0.46	0.27	0.20	0.13	0.27
	May	0.14	0.15	0.07	0.11	0.12
	June	0.20	0.15	0.11	0.25	0.18
	July	0.16	0.11	0.13	0.20	0.15
	Aug	0.22	0.28			0.25
Copper (ppm)	Sep	U	U	U	U	U
	Oct	U	U	U	U	U
	Nov	U	U	U	U	U
	Dec	U	U	U	U	U
	Jan	U	U	U	U	U
	Mar	U	U	U	U	U
	Apr	U	U	U	U	U
	May	U	U	U	U	U
	June	U	U	U	U	U
	July	U	U	U	U	U
	Aug	U	U			U
Iron (%)	Sep	244	1322	1624	1404	1149
	Oct	1996	936	887	746	1141
	Nov	1340	740	643	484	802
	Dec	959	745	577	381	719
	Jan	861	309	238	282	423
	Feb	973	275	188	228	416
	Mar	617	358	251	288	379
	Apr	905	339	256	374	469
	May	652	471	297	343	441
	June	1305	460	380	602	687
	July	1634	532	386	459	753
	Aug	2042	1749			1896
Loss on ignition (%)	Nov	29.96	27.91	25.84	21.34	26.26
	Dec	26.78	n/a	21.55	18.61	23.43
	Jan	29.82	22.21	22.58	19.65	23.57
	Mar	29.60	23.05	18.30	20.06	22.75
	Apr	30.25	31.54	19.29	21.07	25.54
	May	29.21	26.01	24.09	20.37	24.92
	June	40.48	29.00	31.76	20.24	30.37
	July	34.93	24.81	20.93	20.66	25.33

Parameter	Month	300 ft	600 ft	900 ft	1200 ft	Mean
	Aug	35.44	29.73			32.59
Magnesium (%)	Sep	0.73	0.77	0.74	0.75	0.75
	Oct	0.66	0.57	0.66	0.71	0.65
	Nov	0.54	0.56	0.56	0.59	0.56
	Dec	0.55	0.55	0.57	0.67	0.58
	Jan	0.54	0.49	0.63	0.75	0.60
	Mar	0.52	0.51	0.62	0.68	0.58
	Apr	0.62	0.68	0.82	0.82	0.74
	May	0.67	0.71	0.82	0.91	0.78
	June	0.82	0.82	0.90	0.98	0.88
	July	0.87	0.88	0.86	0.91	0.88
	Aug	0.91	0.88			0.90
Manganese (ppm)	Sep	1,191	478	459	354	621
	Oct	1,406	773	585	463	807
	Nov	318	214	200	131	216
	Dec	238	203	142	82	175
	Jan	210	67	41	35	88
	Mar	136	63	33	29	65
	Apr	124	54	32	38	62
	May	84	65	38	33	55
	June	198	84	60	83	106
	July	362	134	95	85	169
	Aug	824	648			736
Moisture (%)	Sep	6.49	4.66	3.56	4.83	4.89
	Oct	6.62	5.77	5.47	4.59	5.61
	Nov	5.23	4.58	4.31	3.86	4.50
	Dec	4.43	4.67	4.03	3.55	4.11
	Jan	4.17	3.78	3.45	3.25	3.66
	Mar	2.73	1.89	1.93	1.71	2.07
	Apr	4.65	3.75	3.07	2.95	3.61
	May	4.84	4.38	4.20	3.69	4.28
	June	5.60	4.50	4.61	3.70	4.60
	July	5.56	4.06	3.61	3.40	4.16
	Aug	6.11	5.74			5.93
Nitrate Nitrogen (%)	Nov	U	U	U	U	U
	Dec	U	U	U	U	U
	Jan	U	U	U	U	U
	Mar	U	U	U	U	U
	Apr	U	U	U	U	U
	May	U	U	U	U	U
	June	U	U	U	U	U
	July	U	U	U	U	U
	Aug	U	U			U

Parameter	Month	300 ft	600 ft	900 ft	1200 ft	Mean
pH	Nov	7.4	7.8	7.9	8.1	7.8
	Dec	8.3		8.6	8.8	8.5
	Jan	8.0	8.7	8.7	8.9	8.6
	Mar	8.6	8.6	8.7	8.6	8.6
	Apr	8.2	8.6	8.8	8.6	8.6
	May	8.3	8.5	8.2	8.5	8.4
	June	8.2	8.3	8.1	8.1	8.2
	July	8.0	8.3	8.7	8.6	8.4
	Aug	7.5	8.2			7.9
Potassium (%)	Sep	0.12	0.09	0.08	0.08	0.09
	Oct	0.29	0.34	0.33	0.22	0.30
	Nov	0.55	0.50	0.61	0.40	0.51
	Dec	0.32	0.29	0.25	0.20	0.27
	Jan	0.35	0.33	0.17	0.15	0.25
	Mar	0.47	0.31	0.18	0.16	0.28
	Apr	0.86	0.33	0.15	0.12	0.37
	May	0.49	0.29	0.12	0.08	0.24
	June	0.47	0.15	0.10	0.12	0.19
	July	0.20	0.12	0.09	0.17	0.14
	Aug	0.36	0.32			0.34
Sodium (%)	Sep	0.13	0.14	0.13	0.12	0.13
	Oct	0.20	0.24	0.32	0.21	0.24
	Nov	0.23	0.26	0.30	0.23	0.26
	Dec	0.23	0.24	0.26	0.23	0.24
	Jan	0.21	0.26	0.29	0.22	0.25
	Mar	0.34	0.30	0.24	0.21	0.27
	Apr	0.33	0.31	0.25	0.16	0.26
	May	0.18	0.33	0.23	0.11	0.21
	June	0.21	0.26	0.17	0.13	0.19
	July	0.16	0.15	0.15	0.15	0.15
	Aug	0.21	0.27			0.24
Sulfur (ppb)	Sep	0.49	0.37	0.38	0.37	0.40
	Oct	0.45	0.34	0.35	0.30	0.36
	Nov	0.36	0.30	0.29	0.25	0.30
	Dec	0.31		0.26	0.23	0.28
	Jan	0.36	0.29	0.23	0.22	0.28
	Mar	0.34	0.29	0.24	0.24	0.28
	Apr	0.44	0.26	0.23	0.22	0.29
	May	0.35	0.32	0.28	0.23	0.30
	June	0.47	0.30	0.28	0.23	0.32
	July	0.36	0.26	0.22	0.23	0.27
	Aug	0.40	0.30			0.35
Total Carbon	Nov	16.4	17.4	16.1	14.8	16.2

Parameter	Month	300 ft	600 ft	900 ft	1200 ft	Mean
(%)	Dec	14.0		12.9	12.7	13.4
	Jan	16.4	11.7	11.9	10.3	12.6
	Mar	19.9	20.1	17.8	16.9	18.7
	Apr	20.6	17.8	17.4	15.2	17.8
	May	22.4	21.6	21.4	19.6	21.2
	June	23.3	21.8	20.1	18.1	20.8
	July	22.7	20.9	18.9	18.6	20.3
	Aug	22.2	20.1			21.1
Zinc (ppm)	Sep	41	44	53	62	50
	Oct	61	86	112	74	83
	Nov	58	160	133	113	116
	Dec	90		98	79	89
	Jan	53	52	48	37	48
	Mar	59	77	40	40	54
	Apr	43	49	38	35	41
	May	87	75	78	47	72
	June	63	68	53	89	68
	July	59	38	68	37	51
	Aug	47	54			51

Periphyton growth was observed one week after start-up in the first 300 ft of the floway and, with the exception of a partial die-off associated with reduced flows on 9/3/08, substantial algae was observed every week thereafter; as evidenced by increased harvest frequency over the duration of the first three quarters (Table 14). During Q3, the majority of algae harvested were from the first 600 ft (approximately 75% of the total harvest) which was observed as dominated by filamentous algae.

In November 2008 and February 2009 algal samples were collected for taxonomic analysis. The November analysis was conducted to determine presence or absence of specific species; while the February sample was analyzed for volumetric composition of species present (cells/mL).

According to the laboratory report, the community structure of the February sample differed greatly from the November sample "by being more abundant in periphytic diatoms, especially *Ulnaria ulna*, *Gomphonema* sp., and *Melosira* cf. *monoliformes*). This can be caused by various factors, one being the drop in temperature that the area experienced during the period when the samples were sent. The top 0-240 ft seemed to be abundant in diatoms, although chlorophytes and cyanobacteria were also abundant in this section. The latter two become less frequent in the section 300-600 ft., leaving a system dominated mainly by diatoms, desmids, *Oedogonium*, and *Ulothrix*. The actual results of the two sample events can be found in Appendix 1.

Water temperature is considered a primary factor influencing Algal Turf Scrubber® performance, and it should be noted that monthly effluent water temperature averaged 2.0°C higher than influent water temperature during Q1 (Table 13). As shown in Table 13, Q2 influent water temperature was approximately 8.6°C less than during Q1. Additionally, mean effluent water temperature was only 0.73°C higher than influent water temperature, and there was a general decrease in the amount harvested over the length of the ATS™. The same is true during Q3 where effluent temperature is only about 0.65°C higher than influent water temperature, and harvest amount decreases along the floway. This is not unexpected as nutrients become depleted, however considerable algae is present even at the lower reaches of the STA-1W pilot floway.

SECTION 5. ATSDEM MODEL REVIEW

The STA-1W Algal Turf Scrubber® (ATS™) pilot system was installed in the summer of 2008, with the intent of facilitating objective evaluation of the ATS™ technology related to its ability to provide reliable, predictable reduction of nutrients—with the primary target being phosphorus—from water associated with releases from the South Florida Water Management District's (SFWMD or District) extensive wetland treatment units known as stormwater treatment areas or STAs. The intent was to pump water from this canal at a rate of up to 20 gpm, and deliver it on a constant flow basis, to the pilot unit, which is 1 foot wide and 1,200 feet long. The quality of influent and effluent, as well as algal productivity, phosphorus areal removal rates, and harvest frequency and characteristics would be monitored weekly for 12 months. The resultant data would be used to develop design criteria which would serve in the development of large scale, commercial level, facilities. This data can most effectively be evaluated by using the first order design and operational model ATSDEM as developed by HydroMentia to first calibrate, and then verify key model parameters. Derivation of the algorithms associated with ATSDEM is presented in Appendix 2 of this text. These parameters include:

1. Best-fit relationship between tissue nitrogen and phosphorus levels and nitrogen and phosphorus water concentrations.
2. Maximum and mean standing crop specifically applicable to the pilot study.
3. Maximum Net Growth Rate (1/hr) for the Turf Community applicable to the specific field conditions encountered.
4. V'ant Hoff Arrhenius coefficient theta (θ) applied in establishing the relationship between growth rate and water temperature.
5. Water temperature when growth rate is highest for the other conditions given.
6. Half rate concentration of total phosphorus (K_{sp})--i.e. the concentration at which the net growth rate is half of the maximum net growth rate.
7. Half rate linear hydraulic loading rate (LHLR) (K_{sh}).

Calibration of the model has been conducted using parameter manipulation applied to the data from the first half of the study period (Q1 and Q2), with parameter values being selected which best fit the data set. Verification is done by applying these selected parameter values to the entire 12 month data set from and comparing projected effluent nutrient levels, growth rates, phosphorus areal removal rates and turf productivity to actual values.

The first set of complete data following system start-up, was collected on 8/20/2008. The final set of complete data for the calibration period was collected on 2/18/2009. Data collected from 8/20/2009 through August 13, 2009 are used for model verification.

TISSUE AND WATER NUTRIENT RELATIONSHIPS

The reliability of the ATSDEM model is dependent upon the ability to project tissue nutrient content based upon nutrient concentrations in the water. While it can generally be expected that tissue nutrient content will increase with increased nutrient concentrations in the water column, the rate of increase, and the general magnitude of tissue levels will vary with each project dependent on (i) water quality characteristics, (ii) floway design (i.e. floway length) and (iii) floway operating conditions (i.e. linear hydraulic loading rate). It is important that this relationship be identified during the pilot phase of the project, as projecting nutrient removal through algal turf uptake relies significantly upon tissue nutrient levels.

During the course of the pilot study, turf samples were collected from each 300 foot section during each harvest. These samples were dried and composited as monthly samples, and delivered to Midwest Laboratories in Nebraska for nutrient analysis. The mean monthly nutrient tissue levels for each 300 foot section were compared to the mean monthly water nutrient concentration at each section. As only influent and effluent samples were taken, changes of concentrations were assumed to be linear down the floway. The resulting data set, with the y-axis being tissue nutrient fraction on a dry weight basis, and the x-axis being mean monthly nutrient concentration, are shown in Table 16.

Table 16: Mean Monthly Total Nitrogen and Phosphorus Water and Tissue Concentrations

Month	Segment	TP Average Monthly Concentration ppb	Tissue P Fraction Average Monthly dry weight	TN Average Monthly Concentration mg/l	Tissue N Fraction Average Monthly dry weight
8/2009	0-300 ft	28	0.0188	3.00	0.0188
9/2008	0-300 ft	52	0.0188	2.88	0.0188
10/2008	0-300 ft	46	0.0193	2.09	0.0193
11/2008	0-300 ft	45	0.0173	2.82	0.0173
12/2009	0-300 ft	28	0.0173	2.55	0.0173
1/2009	0-300 ft	26	0.0173	2.41	0.0173
2/2009	0-300 ft	26	0.0163	2.14	0.0163
8/2009	300-600 ft	25	0.0188	2.98	0.0188
9/2008	300-600 ft	52	0.0148	2.92	0.0148
10/2008	300-600 ft	42	0.0173	2.07	0.0173
11/2008	300-600 ft	41	0.0161	2.68	0.0161
12/2009	300-600 ft	25	0.014	2.60	0.014
1/2009	300-600 ft	23	0.0086	2.40	0.0086
2/2009	300-600 ft	23	0.0086	2.09	0.0086
8/2009	600-900 ft	17	0.0151	2.96	0.0151
9/2008	600-900 ft	51	0.0151	2.96	0.0151
10/2008	600-900 ft	34	0.0167	2.05	0.0167
11/2008	600-900 ft	32	0.0154	2.53	0.0154
12/2009	600-900 ft	19	0.0146	2.64	0.0146
1/2009	600-900 ft	17	0.0089	2.40	0.0089
2/2009	600-900 ft	18	0.0089	2.04	0.0089
8/2009	900-1200 ft	17	0.0152	2.93	0.0152
9/2008	900-1200 ft	51	0.0152	3.00	0.0152
10/2008	900-1200 ft	34	0.0135	2.03	0.0135
11/2008	900-1200 ft	32	0.0122	2.39	0.0122
12/2009	900-1200 ft	19	0.0119	2.68	0.0119
1/2009	900-1200 ft	17	0.0062	2.39	0.0062
2/2009	900-1200 ft	18	0.0135	1.99	0.0135

A series of linear regressions analyses were conducted from this data set. The results are noted in Table 17. For both nitrogen and phosphorus tissue levels, the closest correlation is with total phosphorus concentration in the water. These two graphs are noted as Figures 18 and 19. These two equations have been incorporated within the ATSDEM model as applied to the data set.

Table 17: Linear Regression Nitrogen and Phosphorus Water and Tissue Concentrations

y	x	a	b	r^2
Fraction dw Tissue P	TN concentration mg/l	6.41205E-04	6.92945E-04	0.07
Fraction dw Tissue P	TP concentration ppb	5.74684E-05	4.38651E-04	0.48
Fraction dw Tissue P	N/P concentration ratio	-1.54908E-05	3.72389E-03	0.34
Fraction dw Tissue N	TN concentration mg/l	3.24981E-03	6.28998E-03	0.11
Fraction dw Tissue N	TP concentration ppb	1.95936E-04	7.89298E-03	0.31
Fraction dw Tissue N	N/P concentration ratio	-4.23552E-05	1.83532E-02	0.16

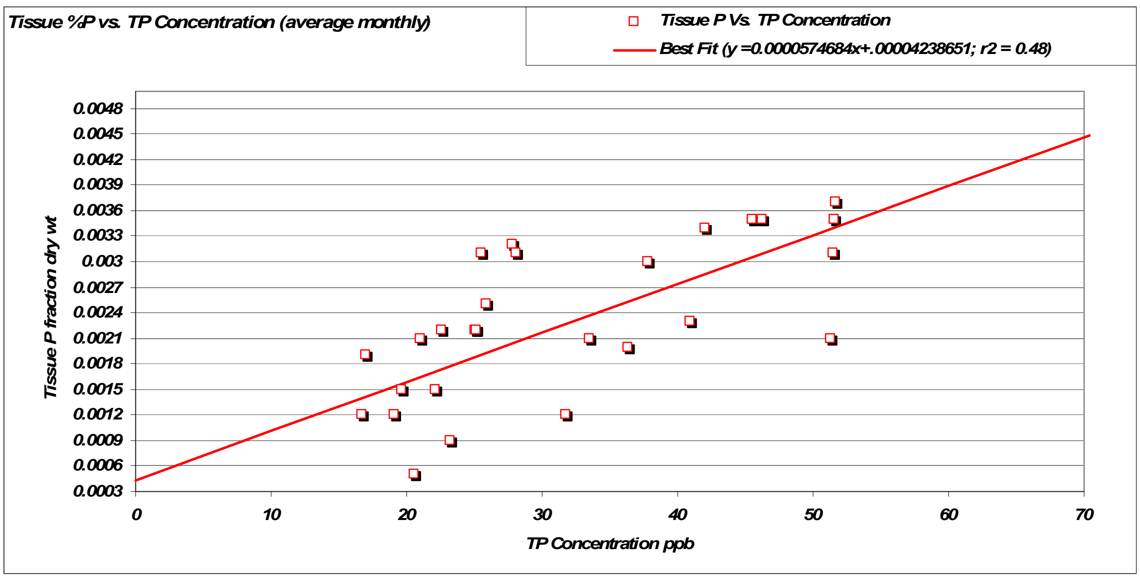


Figure 18: Best Fit Linear Relationship Tissue P Vs. TP Concentration

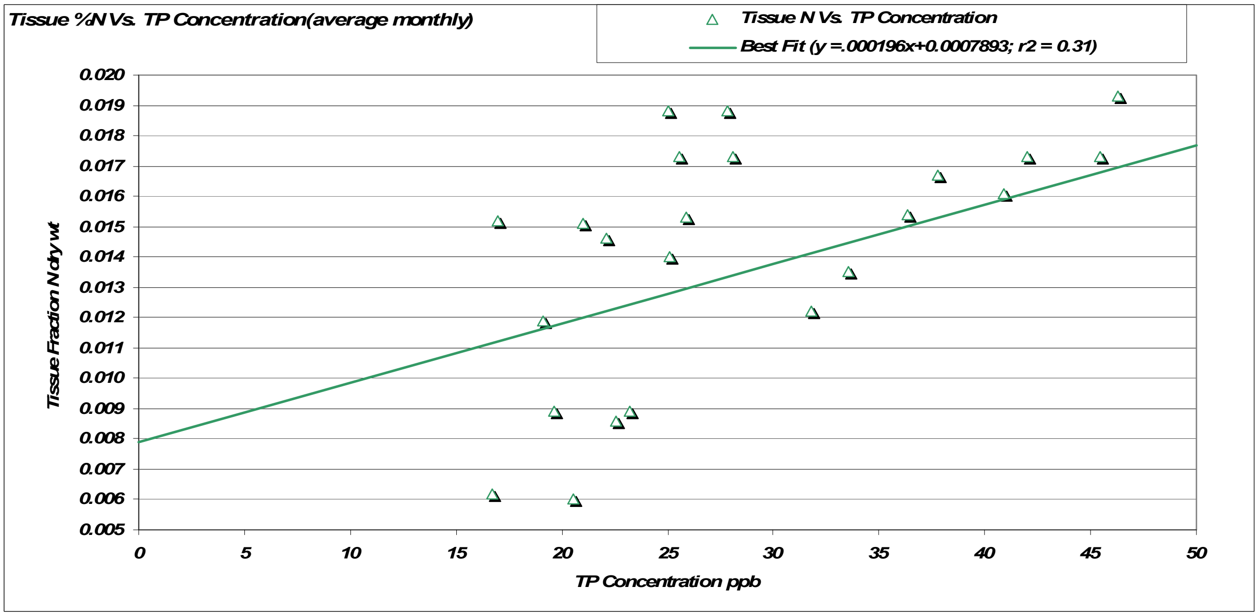


Figure 19: Best Fit Linear Relationship Tissue N Vs. TP Concentration

DETERMINATION OF WORKING STANDING CROP

The performance of any Algal Turf Scrubber® system relies upon the rate of nutrient uptake within a complex algal turf community, combined with chemical and other biochemical processes which may promote removal of nutrients from the water column—e.g. precipitation, denitrification etc. The ATSDEM model presently includes only evaluation of nutrient uptake as measured by harvested and recovered biomass, and the model equations do not directly project the influences of these other chemical and biochemical processes, or the rates of nutrient immigration and emigration associated with such factors as nitrogen fixation and externalized grazing and predation. The model serves to project net community production, applying Monod dynamics on the community level, with recognition that growth rates used are not applied to any one species, or even a specific trophic level, but rather to the entire community. Because it is desired to maximize community production, the nature and extent of the community standing crop both immediately after harvesting (initial crop) and most importantly, just prior to harvesting (maximum standing crop), is key to performance optimization.

The operator of any Algal Turf Scrubber® system therefore is charged with the responsibility of stabilizing a working crop such that it is of sufficient size to ensure optimal nutrient removal, but not so large that successive processes drive the system towards a senescent or quasi-senescent state—senescence in this case meaning the influence of reduction in growth rate, combined with tissue sloughing and necrosis, result in system losses outpacing production. This stabilization is provided through periodic harvesting of a portion of the crop.

The classical production dynamic for ecosystems such as the algal turf community begins with an initially high community growth rate, when crop density is low, with the system then progressing towards a higher density community, with attendant increased sloughing and necrosis and a decline in community growth rate. The complexion of this dynamic is dependent upon a number of variables, including species composition, harvesting frequency, grazing and predation influences, availability of nutrients, space restraints, solar influx, photoperiod, temperature, and influence of other external energies such as that associated with water velocity. Communities which are established upon a foundation of moderately productive algae species which can develop a comparatively high working standing crop have a greater chance of providing higher areal nutrient removal rates than communities built upon a foundation of algae with high rates of sloughing and necrosis and high growth decay rates.

In understanding the production dynamic of algal turf, consider the community net growth rate (μ_{net}) as 1/hr, which can be expressed as:

$\mu_{net} = \mu_0 - \Delta S\, K_d - t\, \phi_{sn}$

Where, μ_0 = initial growth rate 1/hr
ΔS = change in standing crop dry g/m^2
K_d = specific growth decay rate m^2/hr-g
ϕ_{sn} = sloughing and necrosis rate 1/hr^2
t = time in hrs

The influence of this relationship on net biomass development over time can be expressed by a simplified first order growth equation:

$Z_t = Z_o e^{t\mu_{net}}$

Where, Z_0 = initial standing crop dry g/m^2
Z_t = standing crop after time t dry g/m^2

Two hypothetical conditions can be used to demonstrate how these various factors can influence production and nutrient removal performance. In example 1, shown as Figure 20, is considered a community subsidized by high nutrient levels, and characterized by a high initial growth rate, with high decay and sloughing rates. As seen, while biomass increases quickly with time, the curve collapses rapidly, resulting in a comparatively low density standing crop and accordingly, comparatively low levels of phosphorus reduction. With this scenario, optimal harvesting would be done when the phosphorus removal in g/m^2 (see fourth curve in sequence) is beyond the time of apex and approximates the removal after the first hour, or in this example, every 17 hours. At this time, standing crop is at 24.5 dry g/m^2 (a mean standing crop of 18.5 dry g/m^2) and phosphorus removal has reached 59.9 mg/m^2, with the areal P removal rate at 84.6 mg/m^2/day (21.9 g/m^2-year or 195 lb/acre-year). Net production at this time is16.91 g/m^2-day. This community would be rather fragile, and without frequent harvesting would collapse, releasing stored nutrients back to the water column, and becoming vulnerable to replacement by competing communities. This is indicative of a pioneer community, which would not be expected to serve as a long term foundation for a viable algal turf community.

In example 2, shown as Figure 21, the community is characterized by high initial growth rate, but not as high as example 1. It would also have lower rates of decay and sloughing. Such communities would demonstrate the ability to establish a high density standing crop, and accordingly higher nutrient removal rates. Key to such a scenario is the ability of the algal foundation to facilitate a three dimensional base, with efficient sharing of solar influx by a sizable photoautotrophic community, and accordingly, the capability of establishing a functional collection of subsidized grazer, predator, and detrital species sustained without extensive sloughing or accumulation of excessive necrotic material. Such a community is typically envisioned as being subsidized with high nutrient flows, being capable of establishing a base of filamentous green algae mixed with filamentous diatoms and commensal micro algae. As noted, requirements for a floway to develop such a complex system of sufficient viability and density include a combination of a constant, abundant supply of necessary macro and micro nutrients free of naturally occurring or anthropogenic toxins and inhibitors; sufficient heat and solar influx; and additional external energy assistance.

From a review of Figure 21, it is noted that harvesting at hour 203 (8.6 days) at a standing crop of 370 dry g/m^2 (a mean standing crop of 159 dry g/m^2), phosphorus removal has reached 1,785 mg/m^2 when the areal P removal rate reaches a maximum at 211 mg/m^2/day (77.0 g/m^2-year or 687 lb/acre-year). Net production at this time would be 42.2 g/m^2-day. As noted, a system such as this would likely be associated with comparatively high levels of nutrients.

In the field it is not easy to assess hourly changes in production and uptake rates. Rather the timing for system harvest is based upon subjective assessment of observed turf health and includes observed levels of tissue sloughing within the effluent and shifts in pH and DO trends.

During the first 27 weeks of the STA-1W Algal Turf Scrubber® pilot operations, considering documented production rates and calculated growth rates based upon recovered solids from harvesting, it is reasonable to estimate an optimal standing crop density, and accordingly project the growth dynamics curve for the facility. Shown in Table 18 are the findings for the first half of the study period, as used for initial model calibration and for sizing estimation for full scale system. From this table, is noted a mean standing crop density of 43 dry-g/m^2. This value has been used in the ATSDEM model projection for full scale systems as presented in the Basis of Design Report presented in early 2009.

From the Table 18 data, it is possible to use the growth dynamic analyses as represented in Figures 20 and 21 to reflect a generalized profile which could approximate system behavior during the study period. This curve as shown as Figure 22 indicates a stable turf, with a growth rate and standing crop development as might be reasonably expected for a water with such a low nutrient profile. Note that this is a generalized curve which only offers some insight into system dynamics.

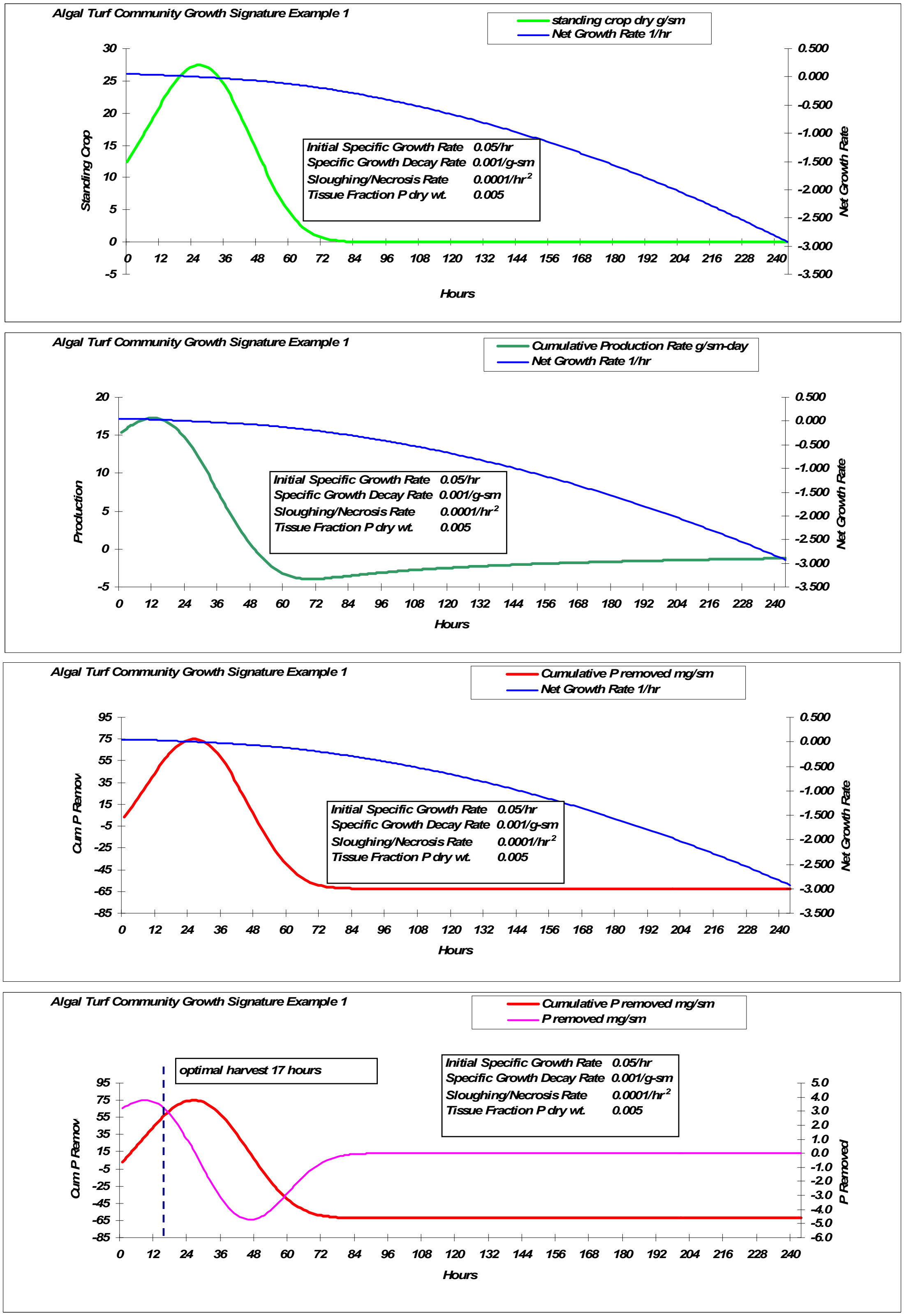


Figure 20: Hypothetical Community Growth Curves Example 1

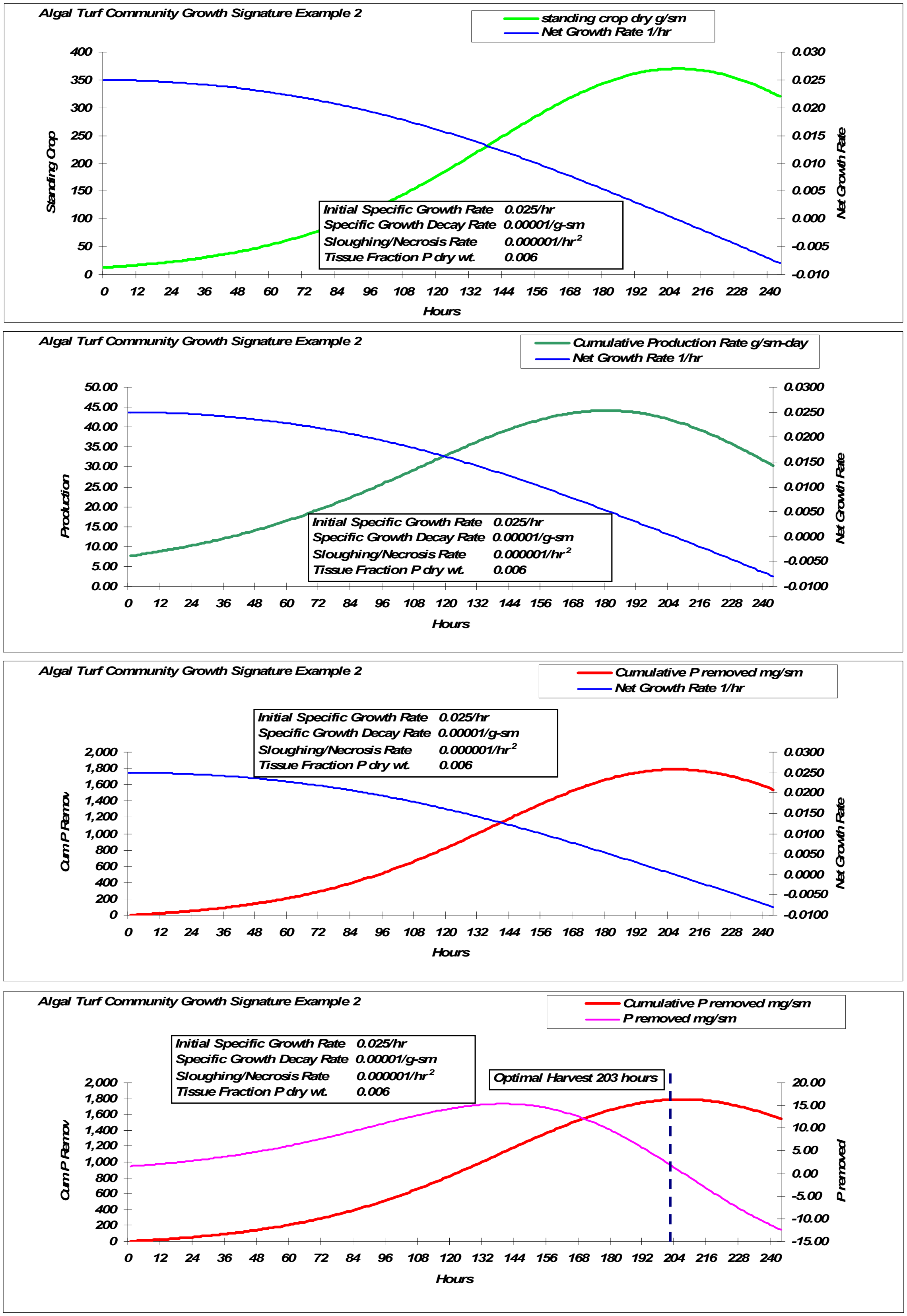


Figure 21: Hypothetical Community Growth Curves Example 2

Table 18: Summary of Performance Based upon Harvest –Study Period STA-1W ATS™ Pilot Study

Harvest Date	Hours between Harvest	Net Growth Rate 1/hr	[1]Initial Standing Crop g/m^2	Standing Crop at harvest g/m^2	Average Standing Crop g/m^2	[2]P removed g/m^2	[2]Areal P Removal Rate mg/m^2-day	[2]Areal P Removal Rate g/m^2-yr	[2]N removed g/m^2	[2]Areal N Removal Rate mg/m^2-day	[2]Areal N Removal Rate g/m^2-yr
9/17/2008	840	0.0048	1.63	88.52	22.42	0.18	5.21	1.90	3.97	113.38	41.38
9/25/2008	192	0.0101	9.84	68.50	31.35	0.15	19.02	6.94	2.56	320.09	116.83
10/8/2008	336	0.0068	7.61	75.23	30.37	0.23	16.46	6.01	1.28	91.29	33.32
10/16/2008	192	0.0105	8.36	62.41	27.96	0.19	23.59	8.61	1.06	132.14	48.23
10/29/2008	312	0.0091	6.93	119.30	41.33	0.35	27.09	9.89	1.98	152.36	55.61
11/12/2008	336	0.0073	13.26	156.44	59.94	0.33	23.27	8.49	2.35	168.10	61.36
11/24/2008	288	0.0070	17.38	132.31	58.15	0.30	25.26	9.22	2.08	173.40	63.29
12/10/2008	384	0.0054	14.70	116.34	35.80	0.26	16.43	6.00	1.69	105.61	38.55
12/23/2008	312	0.0083	12.93	172.19	63.91	0.39	29.67	10.83	2.49	191.54	69.91
1/7/2009	360	0.0059	19.13	161.32	68.27	0.23	15.29	5.58	1.57	104.38	38.10
1/21/2009	336	0.0047	17.92	85.54	43.87	0.14	9.80	3.58	0.90	64.17	23.42
2/4/2009	336	0.0072	9.50	105.91	41.26	0.12	8.65	3.16	0.99	70.50	25.73
2/18/2009	336	0.0066	11.77	109.80	45.11	0.11	8.11	2.96	0.97	69.40	25.33
AVERAGE	**351**	**0.0072**	**11.61**	**111.83**	**43.83**	**0.23**	**17.53**	**6.40**	**1.84**	**135.10**	**49.31**
Maximum	**840**	**0.0105**	**19.13**	**172.19**	**68.27**	**0.39**	**29.67**	**10.83**	**3.97**	**320.09**	**116.83**
Minimum	**192**	**0.0047**	**1.63**	**62.41**	**22.42**	**0.11**	**5.21**	**1.90**	**0.90**	**64.17**	**23.42**
SD	**158**	**0.0019**	**5.00**	**35.95**	**14.70**	**0.09**	**7.94**	**2.90**	**0.88**	**69.52**	**25.37**

[1] Initial standing crop is estimated at 10% of the previous period final standing crop, with the assumption that 90% of the biomass is removed with harvest.
[2] Value calculated from harvested quantities, not from water quality data

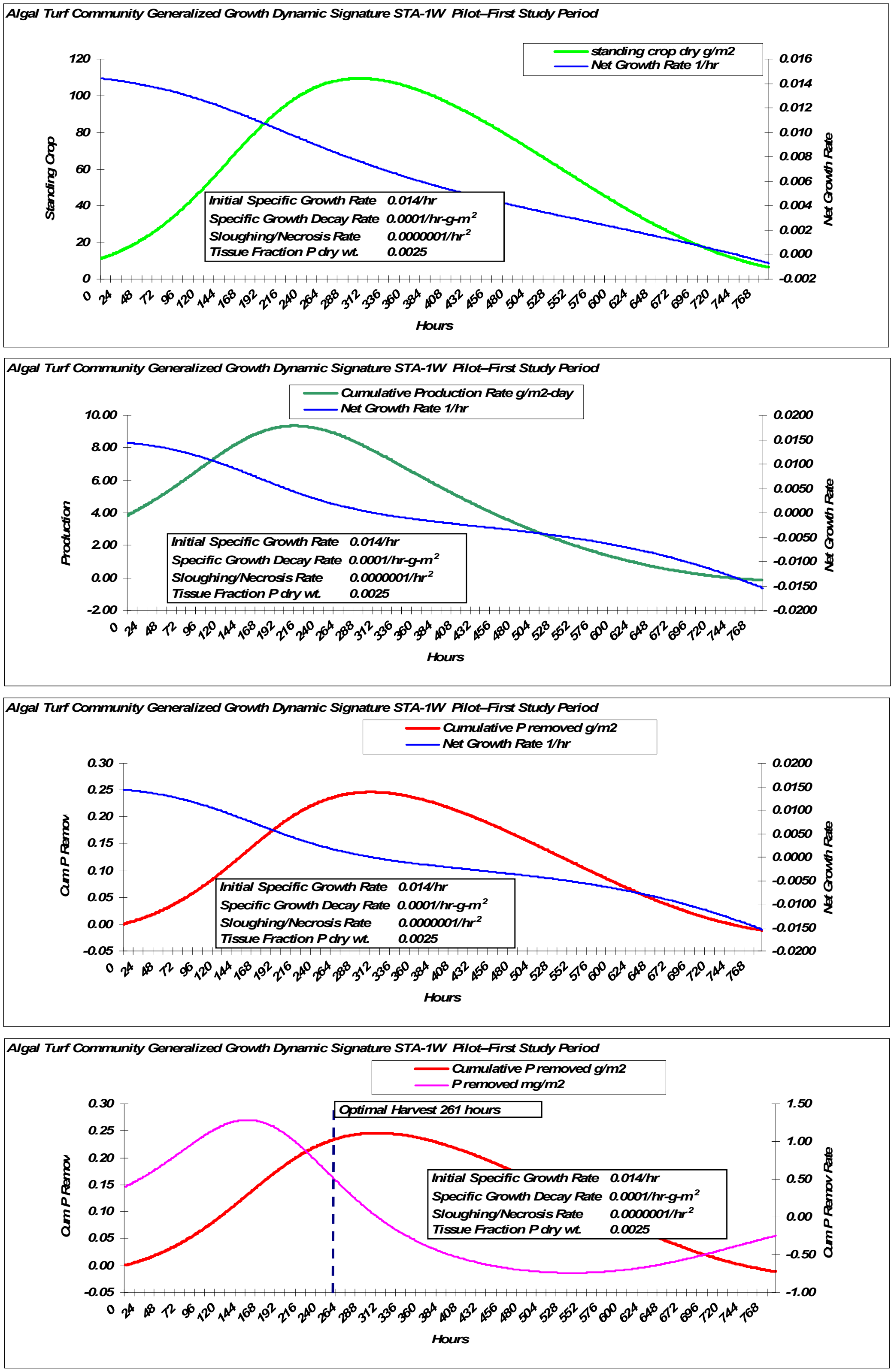


Figure 22: Generalized Community Growth Curves STA-1W Pilot—First Study Period

ESTIMATED REASONABLE MAXIMUM NET COMMUNITY GROWTH RATE

Included in the discussion related to ATSDEM development (see Appendix 2) is an investigation into the key parameters of the Monod relationship:

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

Where μ_{net} is the net growth rate 1/time.
μ_{max} = Maximum possible μ_{net} 1/time
K_s = half saturation constant
S = growth limiting factor

This investigation was applied not to an individual species, but rather to an entire community, i.e. the Algal Turf Community. It was found that the field data developed at the S-154 pilot study in Okeechobee County[9] showed net productivity as measured through harvested biomass followed the Monod model when S was set as total phosphorus and linear hydraulic loading rate (the rate of flow per foot of floway width). In addition μ_{max} was estimated as 0.03/hr to 0.04/hr. Recognizing that production was measured as the accumulated biomass at the end of a certain period between harvests, and considering the discussion in the previous section, μ_{max} as developed actually represents the maximum growth rate over this period, which includes the influence of rate decay and tissue sloughing and necrosis. Therefore it may be considered as the maximum net community growth rate. During the modeling effort as delineated within this text, μ_{max} will be studied within the range of 0.03/hr to 0.04/hr, recognizing that adjustments may be needed to facilitate effective calibration.

ESTIMATED REASONABLE V'ANT HOFF-ARRHENIUS COEFFICIENT

Increased temperatures (within a physiological range) increase rates of biological processes. As a rule of thumb, biological growth rates can be expected to double or nearly double, with a 10º C temperature rise. A mathematical expression of this relationship is:

$\mu_2/\mu_1 = \theta^{(T_2-T_1)}$

where μ_2 and μ_1 = growth rates at temperatures (ºC) T_2 and T_1
θ = V'ant Hoff-Arrhenius constant typically ranging between 1.03 to 1.10.

Theta (θ) was determined to best fit the S-154 conditions at 1.10. It will be considered within the full range during modeling of the STA-1W pilot facility. For this modeling T_2 is an optimal temperature, with T_2 greater than or equal to T_1. In the model if T_i is recorded in the field as greater than T_2, then it is set as equal to T_2 in the model.

ESTIMATED REASONABLE OPTIMAL WATER TEMPERATURE

In subtropical environments such as seen in Florida, optimal growth temperatures may be expected to be relatively high—in a range of perhaps 27-32 ºC. For S-154, the optimal temperature which gave the best model fit was 29.9 ºC. This value will be adjusted around this range during model calibration

[9] HydroMentia (2005) "S-154 Pilot Single Stage Algal Turf Scrubber® Final Report 2005" for SFWMD Contract C-13933

ESTIMATED REASONABLE HALF SATURATION CONSTANTS FOR TOTAL PHOSPHORUS AND LINEAR HYDRAULIC LOADING RATE

As noted, the Monod equation includes a half saturation constant for the rate limiting factor(s). The ATSDEM as developed from S-154 data sets the growth rate as dependent upon two such limiting factors—total phosphorus and linear hydraulic loading rate. The half saturation constant found appropriate for S-154 was 37 µg/L TP, and 9.3 gpm/lf for total phosphorus and linear hydraulic loading rate, respectively. These values will initially be applied to the modeling for the STA-1W pilot facility, to be adjusted as appropriate during the calibration.

MODEL CALIBRATION

As noted, the first half of the applicable data for the first half of the period was used for calibrating the ATSDEM model. Noted in Table 19 are the system results for the entire study period.

It is noteworthy that the initial standing crop for the first week is arbitrarily set, as the system actually begins with the standing crop at zero. Development of a turf therefore depends upon delivery of propagules from the influent flow. Also, during the first five weeks the system was allowed to develop without harvesting, until extensive sloughing was noted. The results of this are noted through high nutrient levels within the effluent. This was done to gain some insight into the turf density which can be supported by the system. Data from week five (9/17/08) indicate the system is likely coming off of the positive sloped portion of the growth and cumulative phosphorus removal curves (Figure 21) and is becoming senescent. Data from these first five weeks are considered anomalous for this reason, and are not used in the calibration exercise. Data from week 6 through 16 are used in model calibration.

The ATSDEM calibration results are noted in Table 20. The selected constants are noted in the upper left hand corner of the table.

MODEL VERIFICATION

The remaining data set was run using ATSDEM, applying the constants developed during calibration. The results are noted in Table 6. The overall ATSDEM results in which actual values of phosphorus and nitrogen effluent concentrations and phosphorus areal removal rates are compared to model projections are shown in Table 22 through 24 and Figures 23 through 25. These projections are considered reasonable considering the inherent challenges in collecting field data. Growth rates and productivity projections were noted to be somewhat conservative when compared to field estimates. Model projections for growth rate over the 12 month period averaged 0.0051/hr (sd = 0.0017/hr) as compared to 0.0084/hr (sd = 0.0021/hr) as a field estimate average. Model projections for productivity over the 12 month period averaged 4.05 dry-g/m^2-day (sd = 2.74 dry-g/m^2-day) as compared to 7.69 dry-g/m^2-day (sd = 2.71 dry-g/m^2-day) as a field estimate average. It is suspected the field productivity estimates were influenced by accumulated carbonate precipitation, which would have been measured as harvested biomass. The high ash content of the harvest supports this proposition. As does the comparatively low nutrient values in the harvested tissue noted during the latter half of the study period. In full planning and design of any full scale program, sufficient flexibility will be needed to ensure this additional inorganic matter is properly managed within any biomass processing unit.

Table 19: Performance Results for 12 month study period

Week	Date Ending	Flow mgd	Alkalinity mg/l as $CaCO_3$	[1]Water T °C	pH influent	pH effluent	TP influent ppb	TP effluent ppb	TN influent mg/l	TN effluent mg/l	[2]Initial Standing Crop g/m^2	Harvest Based Calculated Net Growth Rate 1/hr	Harvest Based Calculated Productivity dry g/m^2-day	Water Quality Based Calculated P Areal Removal Rate dry g/m^2-year
1	8/20/2008	0.0236	180	28.2	7.53	8.61	27	24	2.14	1.95	0.00	0.0048	-	0.17
2	8/27/2008	0.1348	160	31.5	7.64	8.69	31	15	3.89	3.89	[4]	0.0048	-	3.81
3	9/3/2008	0.1705	160	30.9	7.46	8.07	38	40	3.01	2.69	[4]	0.0048	-	-0.63
4	9/10/2008	0.2216	160	27.9	6.97	7.44	45	26	2.50	2.80	[4]	0.0048	-	7.48
5	9/17/2008	0.2238	160	30.9	7.65	8.16	62	89	2.95	3.50	[4]	0.0048	9.11	-10.54
6	9/24/2008	0.2142	160	28.0	7.61	8.31	62	50	3.00	3.10	2.42	0.0101	12.00	4.61
7	10/1/2008	0.2277	140	30.5	7.25	8.40	56	37	3.00	2.70	1.87	0.0080	-	7.48
8	10/8/2008	0.2127	140	28.9	7.52	8.66	41	28	1.20	1.50	[4]	0.0080	3.76	4.87
9	10/15/2008	0.1998	140	28.5	8.37	9.20	56	39	2.55	2.40	2.05	0.0105	6.23	6.04
10	10/22/2008	0.2133	140	26.9	7.38	8.57	44	24	2.28	2.20	1.70	0.0091	-	7.59
11	10/29/2008	0.2208	160	19.4	7.09	8.45	45	29	1.45	1.31	[4]	0.0091	9.15	6.26
12	11/5/2008	0.2053	160	22.1	7.94	8.62	39	27	2.98	1.52	3.26	0.0073	-	4.41
13	11/12/2008	0.2054	160	23.8	7.22	8.42	66	44	2.78	2.42	[4]	0.0073	16.74	8.05
14	11/19/2008	0.1833	160	20.4	7.52	8.15	36	18	2.90	2.90	4.27	0.0070	-	5.86
15	11/25/2008	0.1631	160	20.1	7.29	8.21	50	29	2.91	2.44	[4]	0.0070	8.04	6.09
16	12/3/2008	0.1953	160	18.8	7.8	8.69	35	18	2.38	3.04	3.61	0.0054	-	5.89
17	12/10/2008	0.1653	160	22.4	7.43	8.58	28	22	[3]	[3]	[4]	0.0054	5.21	1.19
18	12/17/2008	0.1510	180	22.7	7.81	9.20	29	22	2.37	2.26	3.18	0.0083	-	1.88
19	12/23/2008	0.1201	180	20.3	7.54	8.42	28	14	[3]	[3]	[4]	0.0083	11.09	2.99
20	12/30/2008	0.1366	180	23.4	7.43	8.68	28	12	2.84	2.82	4.70	0.0059	-	3.88
21	1/7/2009	0.1555	180	22.2	7.68	8.33	27	20	[3]	[3]	[4]	0.0059	8.90	1.95
22	1/14/2009	0.1373	180	22.9	7.66	8.60	25	14	2.00	2.10	4.40	0.0047	-	2.88
23	1/21/2009	0.1433	180	11.0	7.65	8.09	26	14	2.82	2.68	[4]	0.0047	3.78	3.06
24	1/28/2009	0.1403	240	22.8	7.65	8.14	30	13	2.50	5.00	2.33	0.0072	-	4.23
25	2/4/2009	0.1418	240	15.5	7.86	8.40	27	18	2.80	2.15	[4]	0.0072	5.43	2.27
26	2/11/2009	0.1405	240	20.6	7.01	7.78	30	16	2.50	2.40	2.89	0.0066	-	3.50
27	2/18/2009	0.1398	200	20.15	7.42	8.47	27	14	1.14	1.10	[4]	0.0066	6.38	3.24
28	2/25/2009	0.1388	200	19.41	7.42	8.47	25	18	2.24	2.24	12.20	0.0095	4.16	1.74
29	3/4/2009	0.1379	200	17.22	7.68	8.72	27	26	2.68	2.26	10.74	0.0076	7.40	0.29
30	3/11/2009	0.1390	200	21.78	7.67	8.61	26	17	2.54	2.39	10.41	0.0103	5.10	2.24
31	3/18/2009	0.1379	200	22.8	7.4	8.63	21	15	2.56	2.27	11.27	0.009	5.25	1.49
32	3/25/2009	0.1391	200	21.53	7.48	8.52	27	13	2.57	2.40	[4]	0.0090	-	3.45
33	4/1/2009	0.1663	180	25.26	7.35	8.67	28	38	2.57	3.07	6.77	0.0088	8.98	-3.04
34	4/8/2009	0.1462	200	21.65	7.17	8.25	27	15	2.55	2.55	[4]	0.0088	-	3.14
35	4/15/2009	0.1371	240	24.23	7.65	8.47	29	18	2.01	3.04	14.72	0.0067	9.06	2.69
36	4/22/2009	0.1462	200	24.14	7.67	8.42	26	21	2.82	2.49	15.73	0.0103	7.85	1.30
37	4/29/2009	0.1431	200	25.28	7.31	8.29	27	21	2.54	2.53	12.32	0.0087	9.40	1.56
38	5/6/2009	0.1603	200	27.32	7.02	8.1	20	15	2.57	2.53	[4]	0.0087	-	1.46
39	5/13/2009	0.1361	200	27.99	7.63	8.38	20	17	3.17	2.60	12.34	0.0065	6.99	0.75
40	5/20/2009	0.1391	180	26.04	7.38	8.01	19	11	2.67	2.32	12.25	0.0091	6.56	1.96
41	5/27/2009	0.1260	180	26.45	7.64	8.25	25	12	2.36	2.38	7.95	0.0088	6.21	2.90
42	6/3/2009	0.1320	200	27.75	7.61	8.18	24	9.1	2.01	2.09	8.12	0.0131	6.66	3.46
43	6/10/2009	0.1401	200	28.58	7.56	8.24	30	17	1.05	0.96	8.12	0.0111	9.25	3.26
44	6/17/2009	0.1421	200	31.32	7.84	8.22	31	23	2.05	1.96	11.70	0.0152	9.58	2.06
45	6/24/2009	0.1038	200	30.13	7.64	8.02	34	31	1.85	2.44	13.89	0.0084	7.07	0.45
46	7/1/2009	0.1090	200	28.93	7.56	8.24	57	34	3.00	2.06	[4]	0.0084	-	4.37
47	7/8/2009	0.1119	200	30.4	7.64	8.01	39	18	2.65	2.24	9.79	0.0067	3.73	4.17
48	7/15/2009	0.1441	200	30.65	7.8	8.43	39	22	2.76	4.04	9.99	0.0115	11.13	4.36
49	7/22/2009	0.1200	200	29.25	7.6	8.29	48	30	2.64	2.44	14.10	0.0120	8.46	3.76
50	7/29/2009	0.1593	200	30.04	7.22	8.49	46	24	3.04	2.84	[4]	0.0120	-	6.22
51	8/5/2009	0.1341	200	30.04	7.22	8.49	43	22	2.45	2.04	12.82	0.0068	8.15	5.01
52	8/12/2009	0.1341	200	30.33	7.67	8.32	35	19	2.24	2.44	14.10	0.0089	6.99	3.76

[1] Average Water Temperature from weekly site management
[2] Initial Standing Crop set as 10% of standing crop prior to harvest
[3] Composite sample contaminated, no nitrogen data. Phosphorus composites shown for these dates are grab samples.
[4] Initial standing crop between harvest intervals set by final standing crop of the previous week's model run

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Table 20: ATSDEM Calibration Results

T opt ºC	**31.5**
μ_{max} 1/hr	**0.035**
K_{sp} ppb	**40**
K_{sh} gpm/lf	**15**
θ	**1.05**

Sample Numbersn	Week	Week Ending	Actual Effluent TP ppb	Model Effluent TP ppb	Actual Effluent TN mg/l	Model Effluent TN mg/l	μ_{net} Harvest Calculated 1/hr	μ_{net} Model 1/hr	Actual P Removal Rate g/m^2-yr	Model P Removal Rate g/m^2-yr
1	6	9/24/2009	50	41	3.10	2.89	0.0101	0.0096	4.64	7.83
2	7	10/1/2009	37	38	2.70	2.45	0.0068	0.0107	7.70	7.10
3	8	10/8/2009	28	13	1.50	1.01	0.0068	0.0065	4.76	10.53
4	9	10/15/2009	39	38	2.40	2.45	0.0105	0.0092	5.98	6.40
5	10	10/22/2009	24	36	2.20	2.26	0.0091	0.0082	7.57	2.84
6	11	10/29/2009	29	32	1.31	1.37	0.0091	0.0056	6.30	5.12
7	12	11/5/2008	27	31	1.52	2.93	0.0073	0.0059	4.36	3.03
8	13	11/12/2008	44	30	2.42	2.58	0.0073	0.0067	8.05	13.11
9	14	11/19/2009	18	28	2.90	2.85	0.0073	0.0046	5.86	2.46
10	15	11/25/2008	29	29	2.44	2.79	0.0073	0.0050	6.09	6.17
11	16	12/3/2008	18	29	3.04	2.79	0.0073	0.0049	5.89	6.17
		Mean	**31**	**31**	**2.32**	**2.40**	**0.0081**	**0.0070**	**6.11**	**6.43**
		Standard Deviation	**10**	**8**	**0.63**	**0.64**	**0.0013**	**0.0020**	**1.25**	**3.26**
		Standard Error		**10**		**0.53**		**0.0240**		**3.45**

Table 21: ATSDEM Verification Results

T opt ºC	**31.5**
μ_{max} 1/hr	**0.035**
K_{sp} ppb	**40**
K_{sh} gpm/lf	**15**
θ	**1.05**

Sample Number n	Week	Week Ending	Actual Effluent TP ppb	Model Effluent TP ppb	Actual Effluent TN mg/l	Model Effluent TN mg/l	μ_{net} Harvest Calculated 1/hr	μ_{net} Model 1/hr	Actual P Removal Rate g/m^2-yr	Model P Removal Rate g/m^2-yr
1	17	12/10/2008	22	21	-	-	0.0054	0.0049	1.78	5.84
2	18	12/17/2008	22	23	2.26	2.33	0.0083	0.0045	1.88	1.53
3	19	12/23/2008	14	19	-	-	0.0083	0.0036	2.99	2.17
4	20	12/30/2008	12	20	2.82	2.79	0.0059	0.0042	3.88	1.90
5	21	1/7/2009	20	15	-	-	0.0059	0.0036	1.95	3.04
6	22	1/14/2009	14	19	2.10	1.96	0.0047	0.0038	2.69	2.45
7	23	1/21/2009	14	20	2.68	2.78	0.0047	0.0023	3.06	1.49
8	24	1/28/2009	13	25	5.00	2.47	0.0072	0.0045	4.24	1.17
9	25	2/4/2009	18	22	2.15	2.77	0.0072	0.0029	2.27	1.26
10	26	2/11/2009	16	25	2.40	2.47	0.0066	0.0040	3.50	1.71
11	27	2/18/2009	14	20	1.10	1.09	0.0066	0.0035	3.24	1.80
		Mean	**16**	**21**	**2.56**	**2.33**	**0.0064**	**0.0038**	**2.86**	**2.21**
		Standard Deviation	**4**	**3**	**1.11**	**0.58**	**0.0013**	**0.0008**	**0.83**	**1.32**
		Standard Error		**7**		**1.07**		**0.0032**		**2.79**

Table 22: ATSDEM Results through 12 month Study Period—Phosphorus Effluent Concentration

Sample Numbers n	**Actual Influent TP ppb**	Actual Effluent TP ppb	Model Effluent TP ppb	Difference ppb
1	**27**	50	41	9
2	**31**	37	38	-1
3	**38**	28	13	15
4	**45**	39	18	21
5	**62**	24	36	-12
6	**62**	29	32	-3
7	**56**	27	31	-4
8	**41**	44	30	14
9	**56**	18	28	-10
10	**44**	29	29	0
11	**45**	18	29	-11
12	**39**	22	21	1
13	**66**	22	23	-1
14	**36**	14	19	-5
15	**50**	12	20	-8
16	**35**	20	15	5
17	**28**	14	19	-5
18	**29**	14	20	-6
19	**28**	13	25	-12
20	**28**	18	22	-4
21	**27**	16	25	-9
22	**25**	14	20	-6
23	**26**	18	21	-3
24	**30**	26	24	2
25	**27**	17	22	-5
26	**30**	15	15	0
27	**27**	13	17	-4
28	**25**	38	24	14
29	**27**	15	23	-8
30	**26**	18	22	-4
31	**21**	21	17	4
32	**27**	21	21	0
33	**28**	15	14	1
34	**27**	17	16	1
35	**29**	11	13	-2
36	**26**	12	21	-9
37	**27**	9	18	-9
38	**20**	17	24	-7
39	**20**	23	17	6
40	**19**	31	22	9
41	**25**	34	23	11
42	**24**	18	19	-1
43	**30**	22	27	-5
44	**31**	30	21	9
45	**34**	24	11	13
46	**57**	22	27	-5
47	**39**	19	22	-3
Mean	**34**	**22**	**22**	**-1**
Standard Deviation		**9**	**6**	**8**
Standard error of mean difference				**1.16**
95% confidence interval				**2.27**

Table 23: ATSDEM Results through 12 month Study Period—Phosphorus Areal removal Rate

Sample Numbers n	Actual P Removal Rate g/m^2-yr	Model P Removal Rate g/m^2-yr	Absolute Value of Difference g/m^2-yr
1	4.61	7.83	-3.22
2	7.48	7.10	0.37
3	4.87	10.53	-5.66
4	6.04	3.93	2.11
5	7.59	2.84	4.76
6	6.26	5.12	1.14
7	4.41	3.03	1.38
8	8.05	13.11	-5.06
9	5.86	2.46	3.40
10	6.09	6.17	-0.07
11	5.89	6.17	-0.28
12	1.19	5.84	-4.65
13	1.88	1.53	0.36
14	2.99	2.17	0.82
15	3.88	1.90	1.98
16	1.95	3.04	-1.09
17	2.88	2.45	0.43
18	3.06	1.49	1.57
19	4.23	1.17	3.06
20	2.27	1.26	1.01
21	3.50	1.71	1.80
22	3.24	1.80	1.44
23	1.74	0.89	0.85
24	0.29	0.78	-0.49
25	2.24	0.95	1.30
26	1.49	1.38	0.11
27	3.45	2.42	1.03
28	-3.04	1.05	-4.09
29	3.14	1.15	1.99
30	2.69	1.72	0.97
31	1.30	2.43	-1.12
32	1.56	1.47	0.10
33	1.46	1.64	-0.18
34	0.75	1.03	-0.29
35	1.96	1.45	0.51
36	2.90	0.87	2.03
37	3.46	1.34	2.12
38	3.26	1.49	1.76
39	2.06	3.40	-1.35
40	0.45	2.28	-1.83
41	4.37	6.54	-2.17
42	4.17	4.03	0.14
43	4.36	3.15	1.21
44	3.76	5.82	-2.07
45	6.22	9.75	-3.54
46	5.01	4.17	0.84
47	3.76	3.30	0.46
Mean	**3.43**	**3.34**	**0.08**
Standard Deviation	**2.14**	**2.79**	**2.20**
Standard error of mean difference			**0.01**
95% confidence interval			**0.02**

Table 24: ATSDEM Results through 12 month Study Period—Nitrogen Effluent Concentration

Sample Numbers n	**Actual Influent TN mg/l**	Actual Effluent TN mg/l	Model Effluent TN mg/l	Difference mg/l
1	**2.14**	2.70	2.45	0.25
2	**3.89**	1.50	1.01	0.49
3	**3.01**	2.40	2.50	-0.10
4	**2.50**	2.20	2.26	-0.06
5	**2.95**	1.31	1.37	-0.06
6	**3.00**	1.52	2.93	-1.41
7	**3.00**	2.42	2.58	-0.16
8	**1.20**	2.90	2.85	0.05
9	**2.55**	2.44	2.79	-0.35
10	**2.28**	3.04	2.79	0.25
11	**1.45**	2.26	2.33	-0.07
12	**2.98**	2.84	2.79	0.05
13	**2.78**	2.00	1.96	0.04
14	**2.90**	2.82	2.78	0.04
15	**2.91**	2.50	2.47	0.03
16	**2.38**	2.80	2.77	0.03
17	**2.37**	1.14	1.09	0.05
18	**2.84**	2.24	2.21	0.03
19	**2.00**	2.39	2.51	-0.12
20	**2.82**	2.27	2.52	-0.25
21	**2.50**	2.40	2.50	-0.10
22	**2.80**	3.07	2.55	0.52
23	**2.50**	2.55	2.52	0.03
24	**1.14**	3.04	1.96	1.08
25	**2.24**	2.49	2.75	-0.26
26	**2.68**	2.53	2.50	0.03
27	**2.54**	2.53	2.52	0.01
28	**2.56**	2.60	3.14	-0.54
29	**2.57**	2.32	2.62	-0.30
30	**2.57**	2.38	2.33	0.04
31	**2.55**	2.09	1.97	0.12
32	**2.01**	0.96	1.01	-0.05
33	**2.82**	1.96	1.96	0.00
34	**2.54**	2.44	1.77	0.67
35	**2.57**	2.06	2.80	-0.74
36	**3.17**	2.24	2.51	-0.27
37	**2.67**	4.04	2.68	1.36
38	**2.36**	2.44	2.47	-0.03
39	**2.01**	2.84	2.81	0.03
40	**1.05**	2.04	2.35	-0.31
41	**2.05**	2.44	2.15	0.29
Mean	**2.48**	**2.37**	**2.36**	**0.01**
Standard Deviation	**0.56**	**0.56**	**0.51**	**0.44**
Standard error of mean difference				**0.07**
95% confidence interval				**0.13**

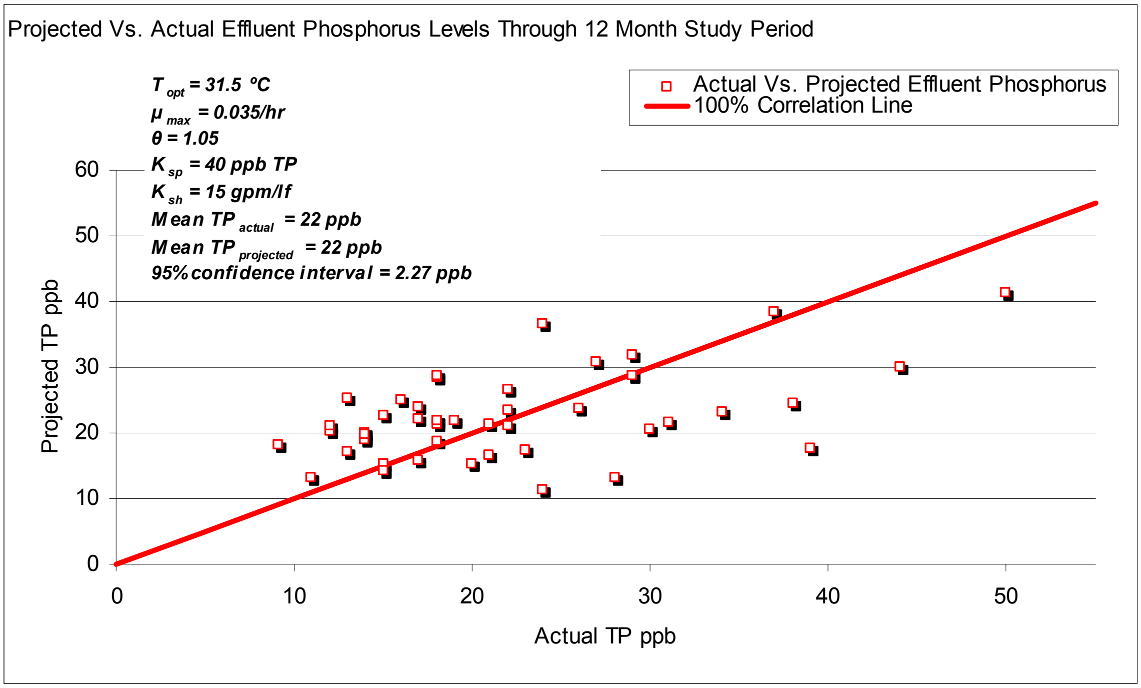


Figure 23: ATSDEM results total phosphorus effluent concentration STA-1W Pilot—12 Month Study Period

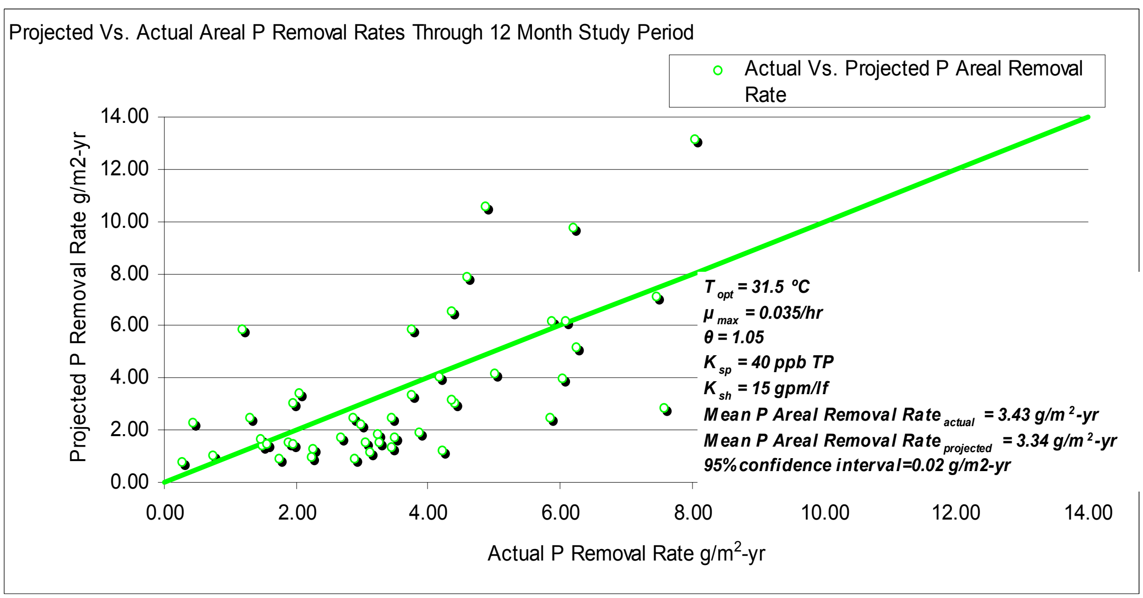


Figure 24: ATSDEM results total phosphorus areal removal rates STA-1W Pilot—12 Month Study Period

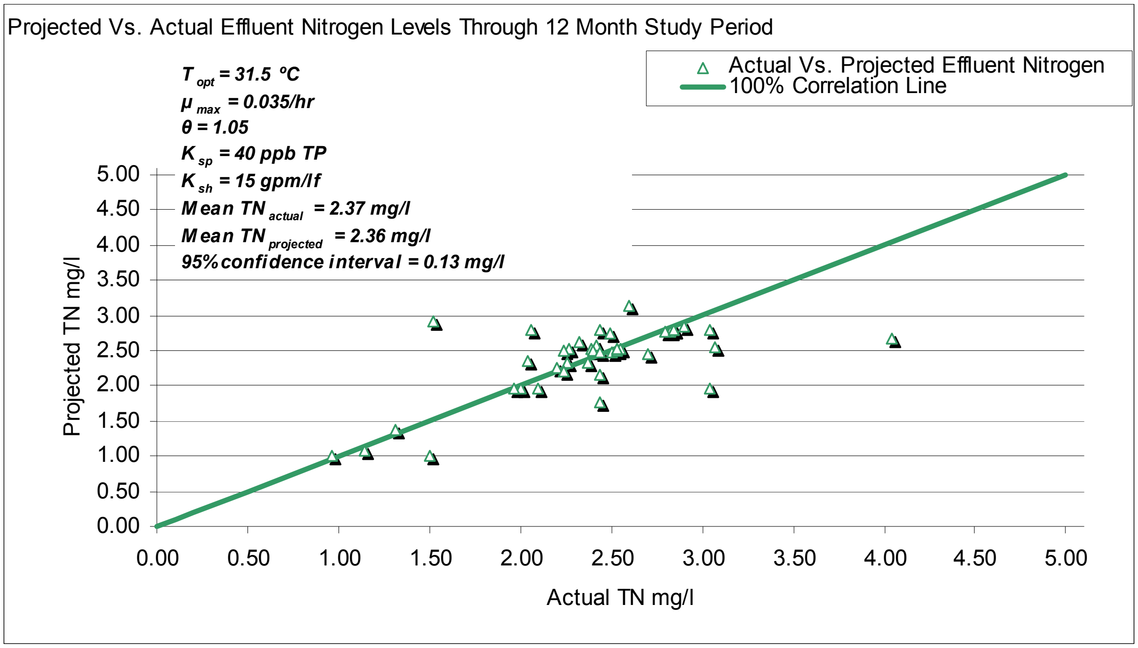


Figure 25: ATSDEM results total nitrogen effluent concentration STA-1W Pilot—12 Month Study Period

ATSDEM FOR EVALUATION OF FULL-SCALE APPLICATIONS

The design and sizing of a full scale facility will depend upon the determined goal of the proposed facility. For example, consider a 1,200 foot long floway, receiving 25 MGD, and with a mean water temperature of 28.5 ºC and an influent total phosphorus concentration of 25 µg/L. When these conditions are evaluated using ATSDEM with a mean standing crop of no more than 43 dry-g/m^2, and the established parameters as previously set, then the sizing can be evaluated using a range of linear hydraulic loading rates (LHLR). As noted in Table 25 and Figure 26, as the LHLR increases from 2.5 gpm/lf to 30 gpm/lf, there is an increase in areal P removal rates, productivity, and effluent phosphorus concentration, with decreases in total area, system width and harvest frequency. It should be noted that the extremes in this evaluation of 2.5 gpm/lf and 30 gpm/lf are outside the range of prior system evaluation, and would not be considered without further in-field testing. Subjectively, it would appear that a LHLR between 10 to 20 gpm/lf would be reasonable for consideration. Certainly, if an effluent microscreen could provide removal of 3-5 µg/L phosphorus, then perhaps 15 gpm/lf would offer the most cost-effective alternative. This is offered as an initial assessment, recognizing a more detailed review will be required once additional site specific performance data is provided.

Table 25: ATSDEM analysis at different Linear Hydraulic Loading Rates (LHLR)

Linear Hydraulic Loading Rate gpm/lf	Flow MGD	Length ft	Width ft	Floway Area acres	Influent TP ppb	Projected Effluent TP ppb	Projected Phosphorus Areal Removal Rate dry-g/m^2-yr	Projected Productivity dry-g/m^2-d	Harvest Period days
2.5	25	1,200	6,944	191	25	11	0.61	1.17	83
5	25	1,200	3,472	96	25	13	1.09	2.02	44
10	25	1,200	1,736	60	25	14	1.91	3.42	27
15	25	1,200	1,157	32	25	15	2.79	4.98	23
20	25	1,200	868	24	25	16	3.22	5.58	19
30	25	1,200	579	16	25	18	3.93	6.59	16

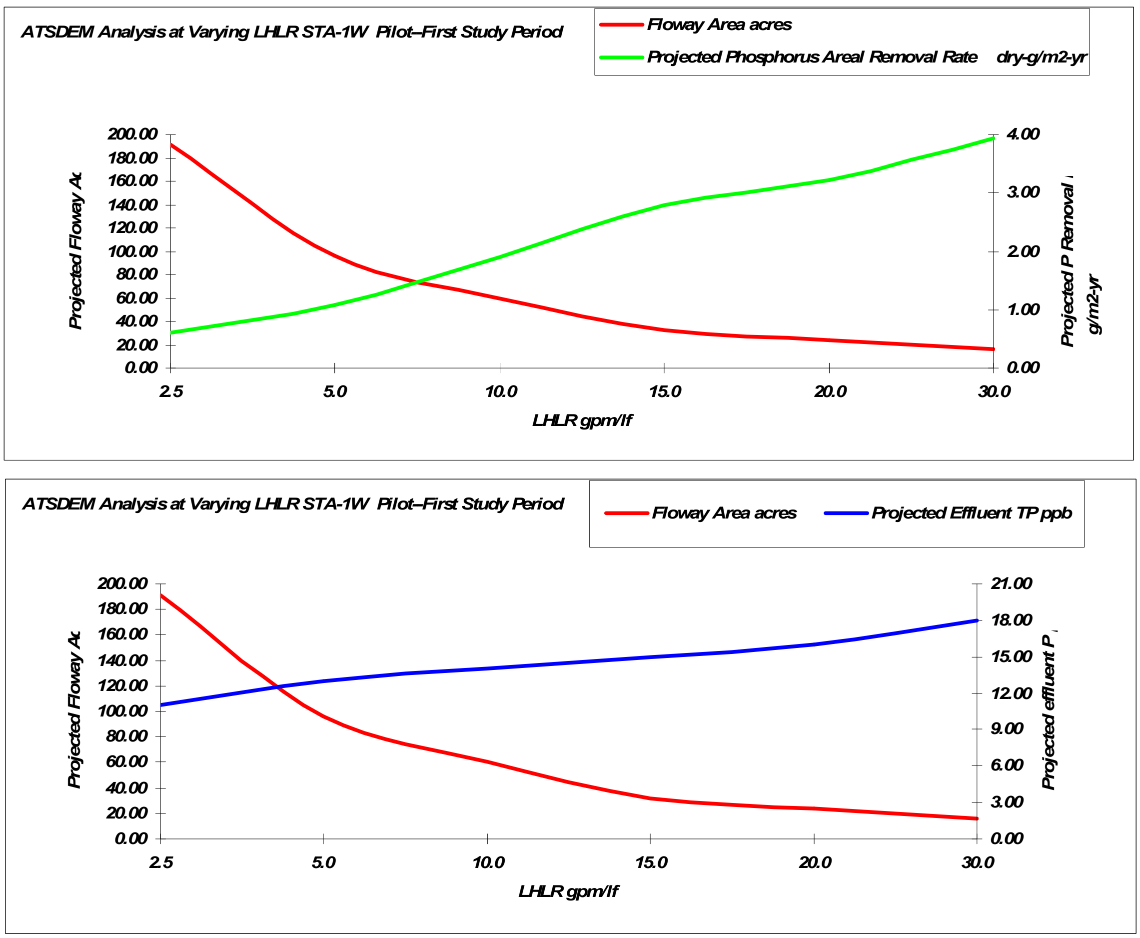


Figure 26: ATSDEM performance analysis at different Linear Hydraulic Loading Rates STA-1W Pilot—First Study Period

APPENDIX 1 – SPECIES IDENTIFICATION

MPU STA-1W
STA-1W effluent Canal
5-Nov-08

Sample/Ecotype/Taxon	0ft	120ft	240ft	360ft	480ft	600ft	720ft	840ft	960ft	1080ft	1200ft	Influent	Outfluent	plankton	benthos	peri/epiphyton	single-cell	c
CYANOPHYCEAE																		
Aphanocapsa hyalina							x								x			
Aphanocapsa punctata		x													x			
Aphanocapsa rivularis				x				x							x			
Chroococcus minor					x	x	x	x					x		x			
Chroococcus sp.			x												x			
Eucapsis carpatica			x				x								x			
Gloeocapsa punctata			x	x		x									x			
Leptolyngbya sp.			x										x			x		
Leptolyngbya tenuis						x										x		
*Lyngbya calcarea**		x	x	x	x	x	x	x	x	x			x			x		
Lyngbya cf. *martensiana*	x										x					x		
Lyngbya martensiana			x			x										x		
Nostoc sp.									x							x		
Oscillatoria cf. *simplicissima*	x		x	x									x			x		
Oscillatoria curviceps								x								x		
Oscillatoria simplicissima					x	x	x									x		
Oscillatoria sp.																x		
Phormidium sp.									x				x			x		
Planktolynbya sp.					x		x				x	x		x				
Pseudanabaena sp.		x												x				
Wolskyella cf. *floridana*							x									x		
Wolskyella sp.	x								x			x				x		
CHLOROPHYCEAE																		
Ankistrodesmus aff. *spiralis*										x	x			x				
Closteriopsis acicularis											x			x				
Coelastrum sp.	x													x				
Desmodesmus cf. *maximus*						x								x				
Desmodesmus intermedius				x									x	x				
Gloeocystis sp.						x		x	x		x			x				
Microspora cf. *quadrata*	x				x			x								x		
Microspora cf. *willeana*					x			x	x							x		
Microspora sp.		x		x		x			x		x		x			x		
Monoraphidium cf. *irregulare*	x													x			x	
Monoraphidium contortum						x								x			x	
Monoraphidium convolutus	x													x			x	
Monoraphidium grifithii											x			x			x	
Monoraphidium minutum						x								x			x	
Monoraphidium sp.				x						x				x			x	
Pediastrum duplex								x	x					x				
Pediastrum tetras				x			x	x			x			x				
Rhizoclonium sp.*	x		x	x	x	x	x	x								x		
Rhombocystis sp.													x	x			x	
Scenedesmus acutus var. *acutus* f. *acutus*									x	x				x				
Scenedesmus acutus var. *acutus* f. *alternans*										x				x				
Scenedesmus cf. *linearis*									x					x				
Scenedesmus dimorphus						x	x	x	x					x				
Scenedesmus linearis					x			x			x			x				
Scenedesmus obtusus var. *obtusus*									x					x				
Scenedesmus ovalternus											x			x				
Stigeoclonium sp.	x								x							x		
Tetrachlorella sp.				x					x					x				
Tetraedron sp.													x	x			x	
Tetrastrum sp.							x							x				

HydroMentia

OEDOGONIOPHYCEAE																
Oedogonium sp.			x	x	x	x	x	x	x		x		x		x	
CHLAMYDOPHYCEAE																
Pleodorina sp.									x					x		
ULVOPHYCEAE																
Ulothrix sp.				x	x										x	
ZYGNEMAPHYCEAE																
Cosmarium cf. *sublobulatum*									x		x			x		
Cosmarium cf. *subtumidum*									x		x			x		
Cosmarium sp.								x		x				x		
Cosmarium trilobulatum					x	x			x					x		
Spirogyra sp.	x					x							x		x	
EUGLENOPHYCEAE																
Rhabdomonas sp.			x		x							x		x		x
Trachelomonas cf. *armata*								x						x		x
Trachelomonas cf. *hispida*							x						x	x		x
Trachelomonas cf. *oblonga*						x								x		x
Trachelomonas sp.		x		x								x	x	x		x
COSCINODISCOPHYCEAE																
Cyclotella sp.	x	x	x				x		x						x	x
Melosira cf. *lineata*							x	x							x	
Melosira cf. *monoliformes*	x		x		x										x	
Melosira varians	x		x	x	x	x	x	x			x				x	
FRAGILARIOPHYCEAE																
cf. *Tabellaria*		x													x	
Diatoma sp.			x	x		x									x	
Fragilaria cf. *capucina*					x										x	
Fragilaria cf. *utermoehlii*					x										x	
Fragilaria cf. *vaucheriae*									x						x	
Fragilaria sp.	x	x	x				x	x			x		x		x	
Fragilariforma sp.	x	x	x	x	x	x	x			x			x		x	
Synedra acus	x	x			x	x	x	x					x		x	x
Synedra cf. *delicatissima*				x											x	x
Synedra cf. *rumpens*				x											x	x
Synedra rumpens							x								x	
Synedra sp.					x		x	x	x	x	x				x	
*Ulnaria ulna**	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x

BACILLARIOPHYCEAE															
Achnanthes sp.			x	x	x			x		x				x	x
Amphora sp.	x	x									x			x	x
Caloneis sp.	x	x	x				x	x			x			x	x
Cocconeis cf. *placentula*									x					x	x
Cocconeis sp.	x		x	x	x		x			x		x		x	x
Cymbella aff. *affinis*								x						x	x
Diploneis sp.							x		x		x			x	x
Encyonema cf. *minutum*									x					x	x
Encyonema cf. *prostratum*	x			x		x					x			x	x
Encyonema prostratum							x							x	x
Encyonema sp.		x	x		x								x	x	x
Epithemia cf. *sorex*									x					x	x
Epithemia sp.				x	x									x	x
Eunotia cf. *minor*				x						x	x			x	
Eunotia sp.					x	x								x	
Frustulia sp.		x	x	x	x			x	x					x	x
Gomphoneis cf. *herculeana*									x					x	x
Gomphoneis sp.					x			x						x	x
Gomphonema cf. *parvulum*	x			x				x						x	x
Gomphonema parvulum						x								x	x
Gomphonema sp.		x	x	x		x	x		x	x	x			x	x
Hantzschia cf. *virgata*	x													x	x
Hantzschia sp.*		x	x	x	x	x	x	x	x		x		x	x	x
Navicula cf. *capitoradiata*							x							x	x
Navicula cf. *gregaria*			x							x			x	x	x
Navicula cf. margalithi			x	x			x							x	x
Navicula cryptocephala	x	x		x	x		x			x				x	x
Navicula margalithi		x												x	x
Navicula rhyncocephala	x	x	x							x				x	x
Navicula sp.	x								x					x	x
Nitzschia cf. *amphibia*		x											x	x	x
Nitzschia cf. *dissipata*							x			x	x			x	x
Nitzschia cf. *lanceolata*						x			x	x				x	x
Nitzschia cf. *palea*	x		x	x		x	x				x		x	x	x
Nitzschia palea		x								x				x	x
Nitzschia sp.	x		x	x					x	x	x	x		x	x
Pinnularia sp.	x								x					x	x
Rhoicosphenia sp.					x									x	x
Rhopalodia cf. *novae-zelandiae*				x			x							x	x
Rhopalodia cf. *operculata*				x	x				x					x	x
Rhopalodia operculata		x				x	x	x					x	x	x
Rhopalodia sp.								x	x	x	x			x	x
Stauroneis sp.							x							x	x
Stenopterobia cf. *delicatissima*		x												x	x
Surirella cf. *tenera*										x	x			x	x

abundant
superabundant

HydroMentia

The community structure of this sample differed greatly from the prior sample sent in November by being more abundant in periphytic diatoms, especially *Ulnaria ulna*, *Gomphonema* sp., and *Melosira* cf. *monoliformes*). This can be caused by various factors, one being the drop in temperature that the area experienced during the period in which the samples were sent. The top 0-240 ft seems to be abundant with diatoms, though chlorophytes and cyanobacteria are also very frequent in these portions. The latter two become less frequent in the section 360-600 ft., leaving a system dominated mainly by diatoms, desmids, *Oedogonium*, and *Ulothrix*.

MPU STA-1W
STA-1W effluent Canal
4-Feb-09

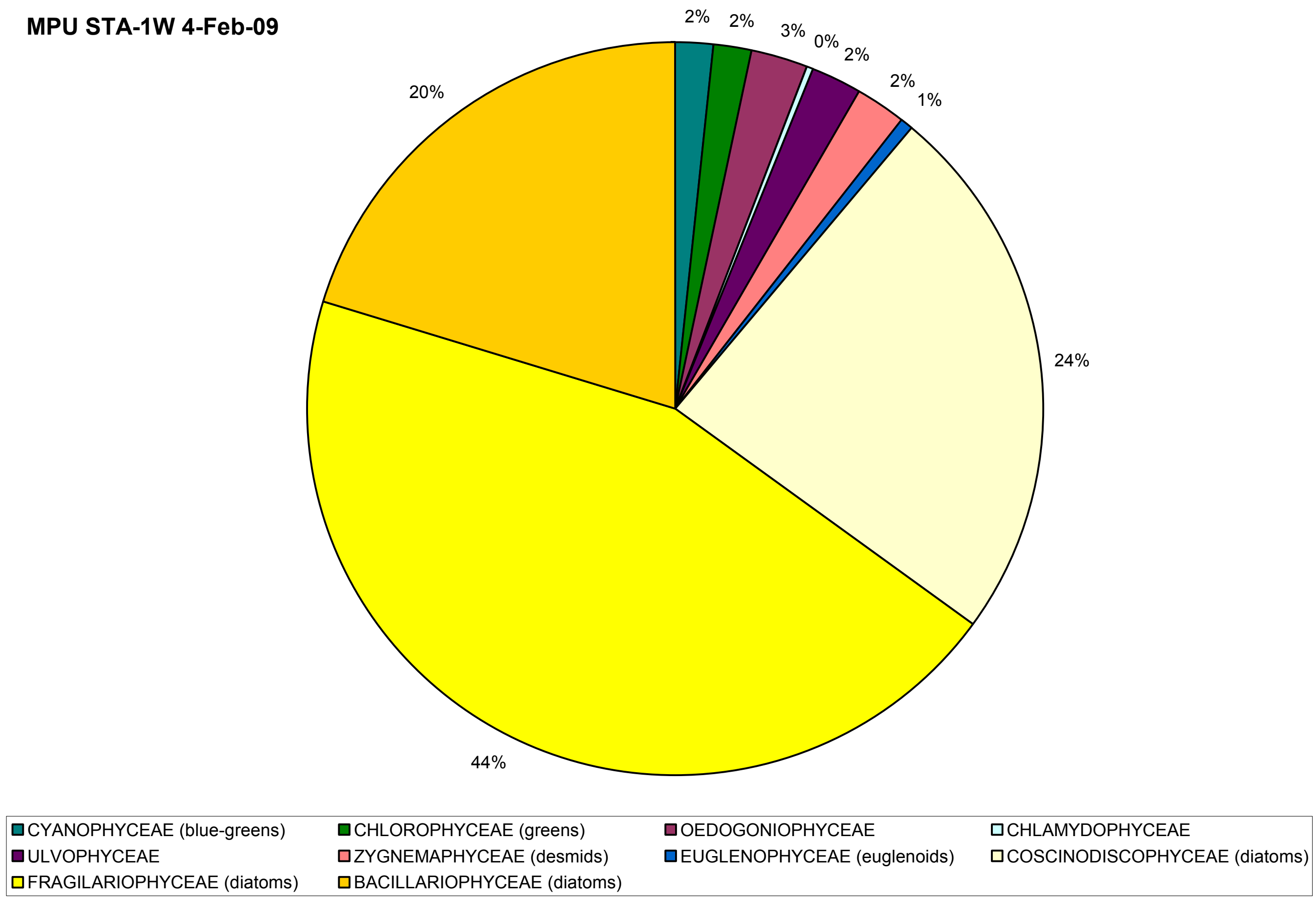
	0ft	120ft	240ft	360ft	480ft	600ft	Total	Ind per mL*	Ranking**
Fields of view counted	5	3	4	6	5	4	27		
CYANOPHYCEAE									
Chroococcus minor			1	2			3	10,655,091	
Chroococcus sp.		2	1				3	10,655,091	
Eucapsis carpatica			2				2	7,103,394	
Gloeocapsa punctata		2		1			3	10,655,091	
Leptolyngbya sp.						2	2	7,103,394	
*Lyngbya calcarea**	1	3	3		2	1	10	35,516,969	
Lyngbya cf. *martensiana*	1					1	2	7,103,394	
Phormidium sp.			2	3	2	1	8	28,413,575	
Planktolynbya sp.			1		2	2	5	17,758,485	
Pseudanabaena sp.			2			1	3	10,655,091	
Wolskyella sp.				2			2	7,103,394	
CHLOROPHYCEAE									
Cladophora sp.	2				1	5	8	28,413,575	
Closteriopsis acicularis	5						5	17,758,485	
Coelastrum sp.	1						1	3,551,697	
Gloeocystis sp.				1			1	3,551,697	
Microspora sp.	6						6	21,310,182	
Rhizoclonium sp.*		1	3			6	10	35,516,969	
Scenedesmus linearis	1						1	3,551,697	

Scenedesmus ovalternus	1						1	3,551,697	
Stigeoclonium sp.	2						2	7,103,394	
Tetraedron sp.	1		1				2	7,103,394	
								-	
OEDOGONIOPHYCEAE								-	
Oedogonium sp.	1			2		3	6	21,310,182	
								-	
CHLAMYDOPHYCEAE								-	
Pleodorina sp.				1			1	3,551,697	
								-	
ULVOPHYCEAE								-	
Ulothrix sp.				1		4	5	17,758,485	
								-	
ZYGNEMAPHYCEAE								-	
Cosmarium sp.			2				2	7,103,394	
Spirogyra sp.		1		3	3	2	9	31,965,272	
								-	
EUGLENOPHYCEAE								-	
Lepocinclis sp.		1					1	3,551,697	
Trachelomonas sp.			1		1		2	7,103,394	
								-	
COSCINODISCOPHYCEAE								-	
Cyclotella sp.			3		1		4	14,206,788	
Melosira cf. *monoliformis*	30	78	10	30	5	10	163	578,926,598	3
Melosira varians	1		1				2	7,103,394	
								-	
FRAGILARIOPHYCEAE								-	
Fragilaria sp.	1	3	8	15	6	10	43	152,722,968	10
Fragilariforma sp.	6	3	2	4	3		18	63,930,545	
Synedra acus	6	12		9	2	4	33	117,205,998	
Synedra ulna cf. var. *biceps*	6						6	21,310,182	

Synedra ulna var. *ramesi*	2						2	7,103,394	
Synedra sp.	135						135	479,479,084	6
*Ulnaria ulna**	86	75	111	98	91	49	510	1,811,365,430	1
								-	
BACILLARIOPHYCEAE								-	
Achnanthes sp.			110				110	390,686,661	7
Amphora sp.	10		2				12	42,620,363	
Cocconeis cf. *placentula*	7						7	24,861,878	
Cocconeis sp.			1				1	3,551,697	
Cymbella aff. *affinis*		3			1		4	14,206,788	
Encyonema sp.	1	1	5				7	24,861,878	
Epithemia sp.			1				1	3,551,697	
Gomphoneis sp.	1		2	1	2		6	21,310,182	
Gomphonema cf. *parvulum*		2		5		52	59	209,550,118	9
Gomphonema parvulum			4	20			24	85,240,726	
Gomphonema sp.	2		4	118	117	150	391	1,388,713,496	2
Navicula cf. *gregaria*	2						2	7,103,394	
Navicula cf. *margalithi*	1						1	3,551,697	
Navicula cryptocephala	2						2	7,103,394	
Navicula sp.	6	2	124	15	4	3	154	546,961,326	4
Nitzschia sp.	102	8	9	15	10	2	146	518,547,751	5
Rhoicosphenia sp.			11	8	14	40	73	259,273,875	8
Rhopalodia cf. *operculata*	1						1	3,551,697	
Rhopalodia operculata						1	1	3,551,697	
Rhopalodia sp.			1				1	3,551,697	
Surirella cf. *tenera*	1	1					2	7,103,394	
Total	**431**	**198**	**428**	**354**	**267**	**349**	**2027**	**7,199,289,661**	

* Utermohl Method
** modified Lobo (1984)
1-10 (abundance)

MPU STA-1W 4-Feb-09



APPENDIX 2 – 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 mean 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.

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

or

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

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

$$\ln(S_i/S_0) = -kt \;\; \text{or} \;\; S_i = S_0 e^{-kt} \qquad \text{Equation 3}$$

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.

$$Z_t = Z_0 e^{mt} \qquad \text{Equation 4}$$

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

$$m = m_{max} S/(K_s + S) \qquad \text{Equation 5}$$

Where m_{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 $m = ½ m_{max}$.

Considering the flow dynamic of the ATS™, the system may be viewed as a plug flow system. Recognizing that the mean 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:

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

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 **m.** 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.

$$m_{opt}/m_1 = Q^{(T_{opt}-T_1)} \quad \text{or} \quad m_1 = m_{opt}/Q^{(T_{opt}-T_1)} \qquad \textbf{Equation 7}$$

Where m_{opt} is the growth rate for given **S** at the optimal growing temperature ^{o}C, $\mathbf{T}_{opt}$, and m_1 is the growth rate for the same given **S** at some temperature ^{o}C, $\mathbf{T_1}$, when $\mathbf{T_1 < T}_{opt}$, and **Q** is an empirical constant ranging from 1.03 to 1.10.

$$S_{y1} = S_{y0} - \{[S_t\{Z_{ave}e^{[m(y1-y0)/v]}[1/Q^{(T_{opt}-T_1)}] - Z_{ave}\}]/[q(y_1-y_0)/v]\} \qquad \textbf{Equation 8}$$

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 **Q.**

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

$$S_{y1} = S_{y0} - \{[S_t\{Z_{ave}e^{[m_{max}S_{y0}/(Ks+S_{y0})][(y_1-y_0)/v]}[1/Q^{(T_{opt}-T_1)}] - Z_{ave}\}]/[q(y_1-y_0)/v]\} \qquad \textbf{Equation 9}$$

Estimation of m_{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]/m,** as the dependent variable is the preferred of the three. In such a plot, m_{max} is represented as the inverse of the slope of the linear equation:

$$[S]/m = (K_s/m_{max}) + (1/m_{max})[S] \qquad \textbf{Equation 10}$$

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

Plotting the single flow data set using the Hanes method is helpful at providing some indication of expected general range of m_{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 A2-1, 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.

4. Growth rate is calculated by $\mathbf{ln(Z_t/Z_0)\ /t = m}$ with $\mathbf{Z_0}$**,** 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 **Q=** 1.10.
6. Substrate concentration is set as the mean between influent and effluent concentrations.

Scattergrams of the total phosphorus, total nitrogen, available carbon, and linear hydraulic loading rate with calculated growth rate are noted in Figures A2-1 to A2-4. 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 $\mathbf{K_s}$**.** 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:

$$\mathbf{m = m_{max.}\ \{[P]/(K_p+[P])\}\ \{[N]/(K_n+[N])\}\ \{[CO_2]/(K_C+[\ CO_2])\}\ldots\ Equation\ 11}$$

Noted in Table A2-2 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 A2-5 through A2-10. What is more difficult to explain are the negative values of $\mathbf{K_s}$, most notable during the October to December period. Initially, this might be interpreted as indication of inhibition at high concentrations. However, at these concentrations (500-1,000µg/L), 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. 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 is not as clear.

Table A2-1: 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

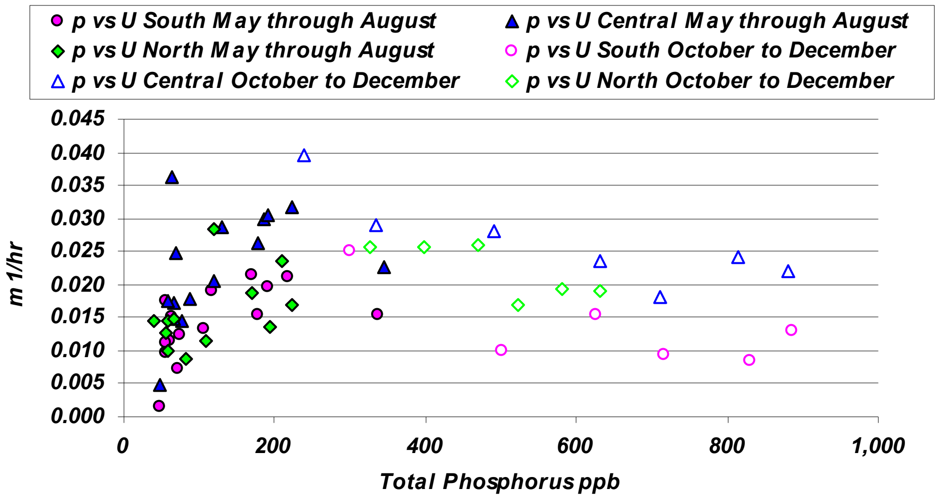


Figure A2-1: Total phosphorus Vs. calculated growth rate adjusted POR data set

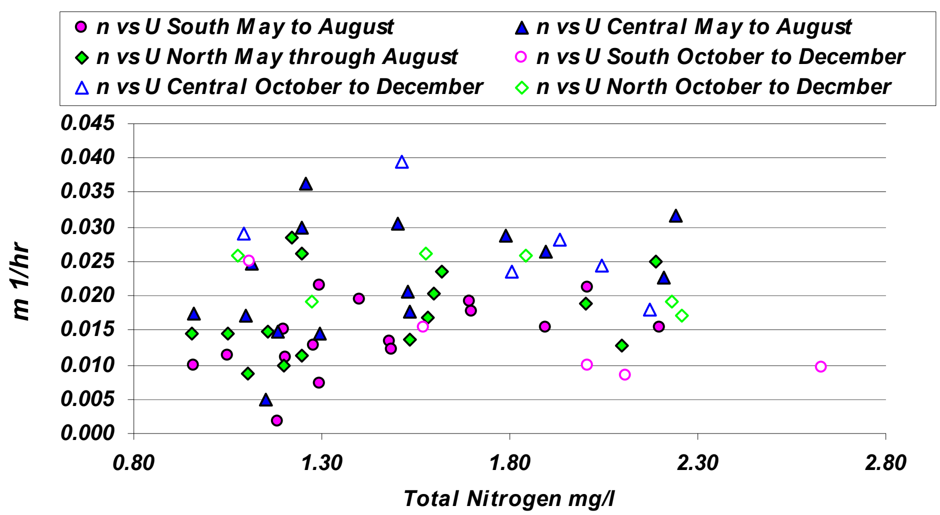


Figure A2-2: Total nitrogen Vs. calculated growth rate adjusted POR data set

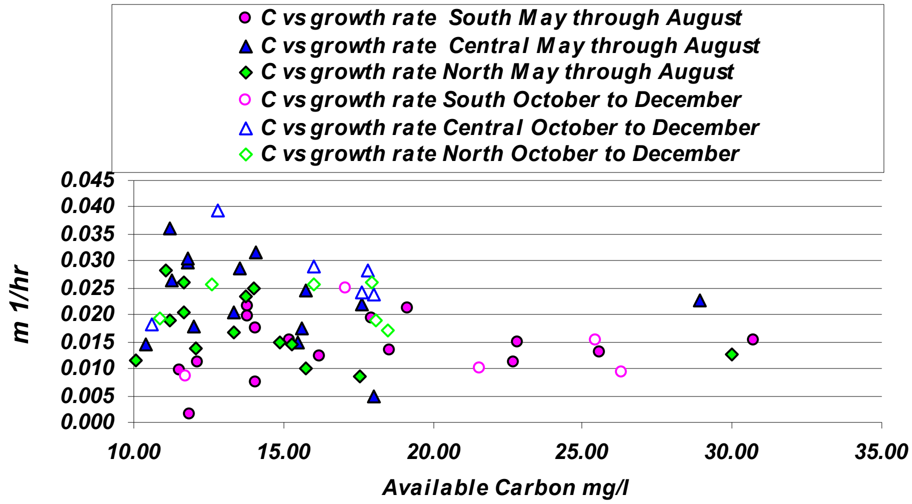


Figure A2-3: Available Carbon Vs. calculated growth rate adjusted POR data set

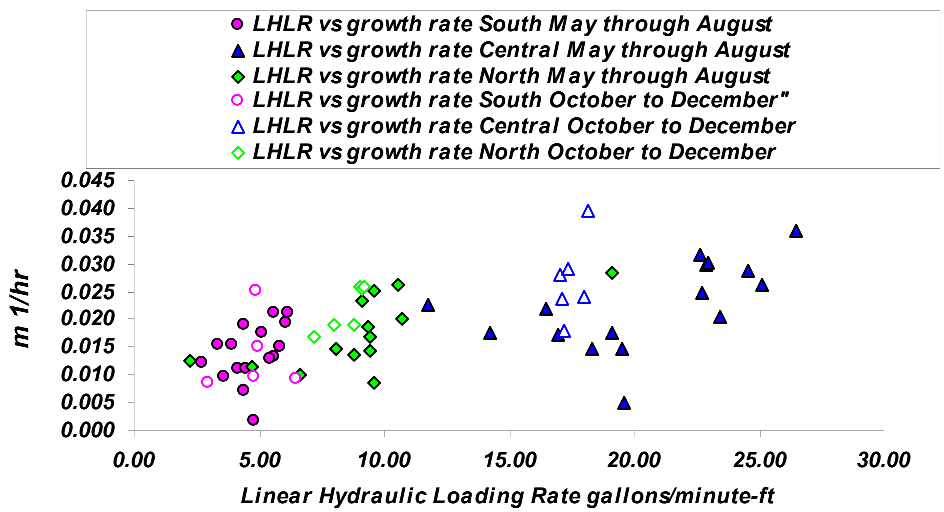


Figure A2-4: Linear Hydraulic Loading Rate Vs. calculated growth rate adjusted POR data set

Table A2-2: Results of Hanes analysis

Floway	Time Period	Parameter	r^2	$m_{max\ 1/hr}$	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**

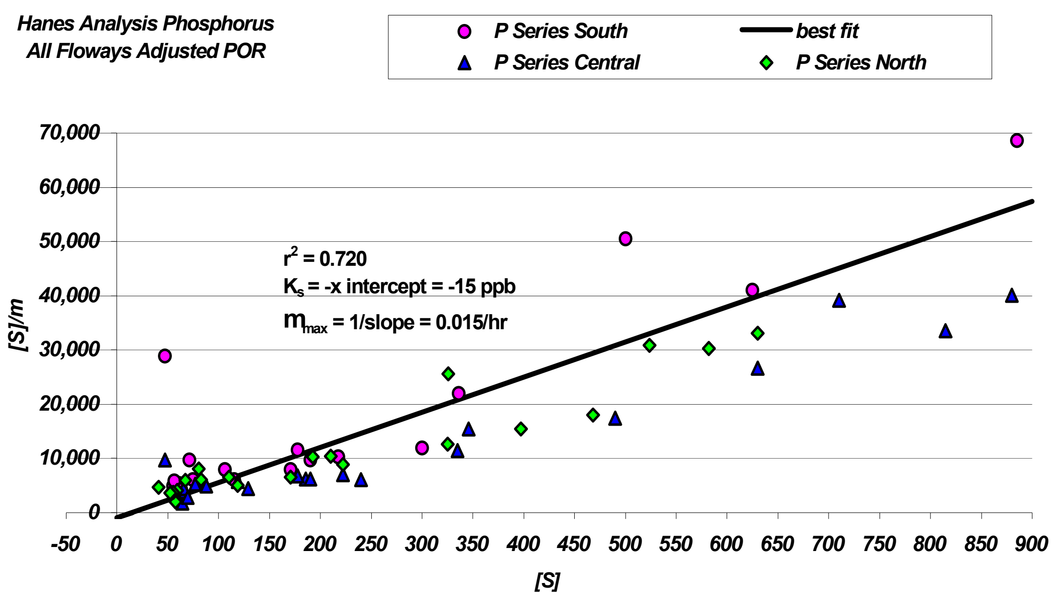


Figure A2-5: Hanes plot total phosphorus all floways over adjusted POR

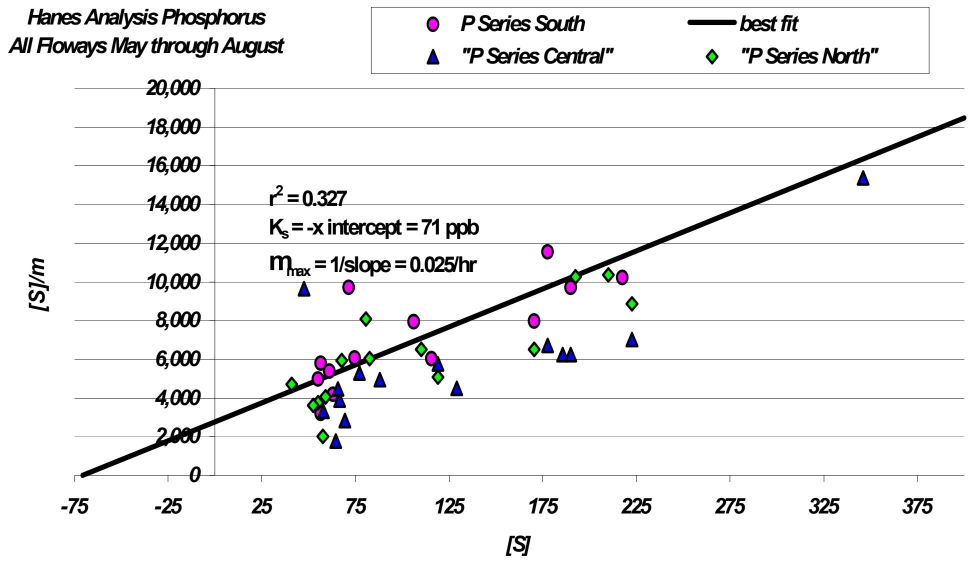


Figure A2-6: Hanes plot total phosphorus all floways May through August

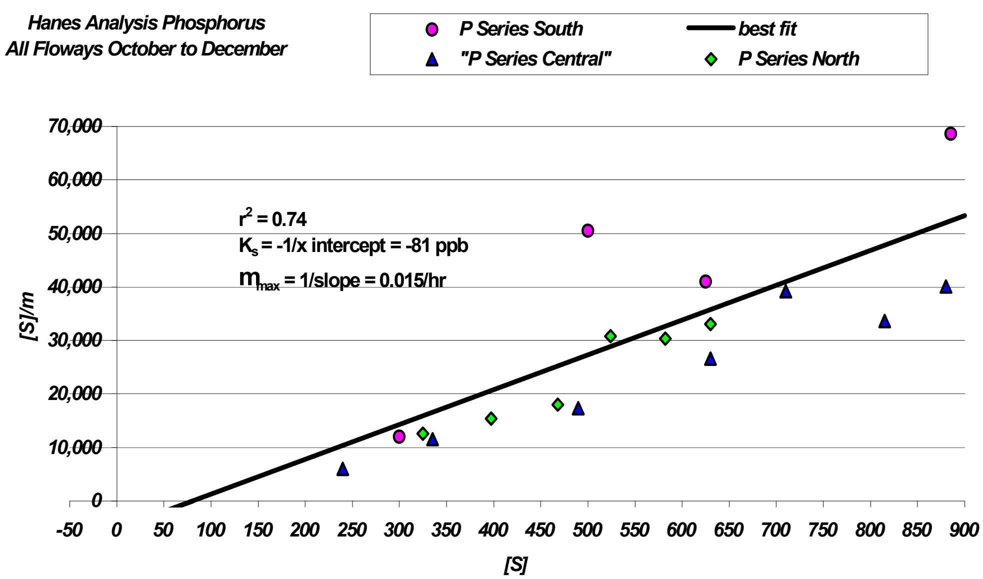


Figure A2-7: Hanes plot total phosphorus all floways October to December

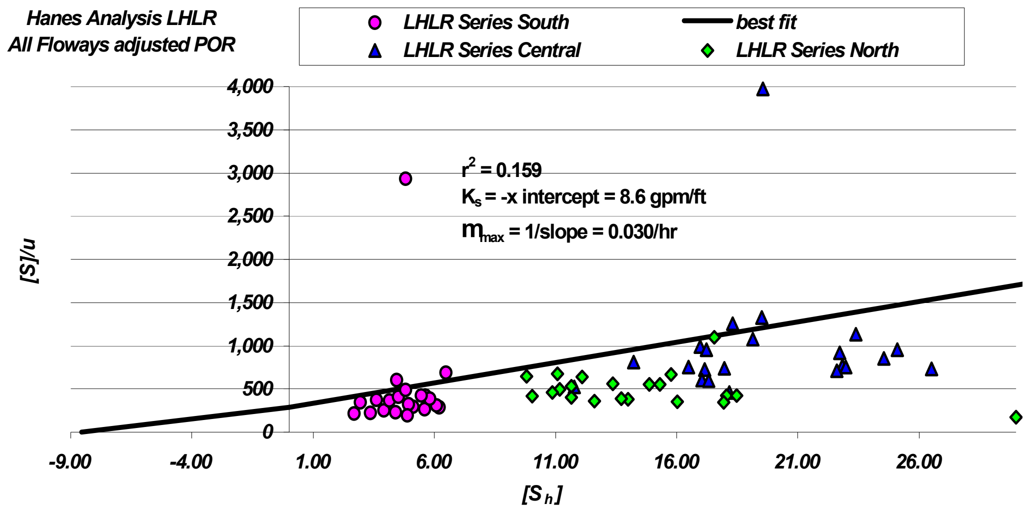


Figure A2-8: Hanes plot LHLR all floways over adjusted POR

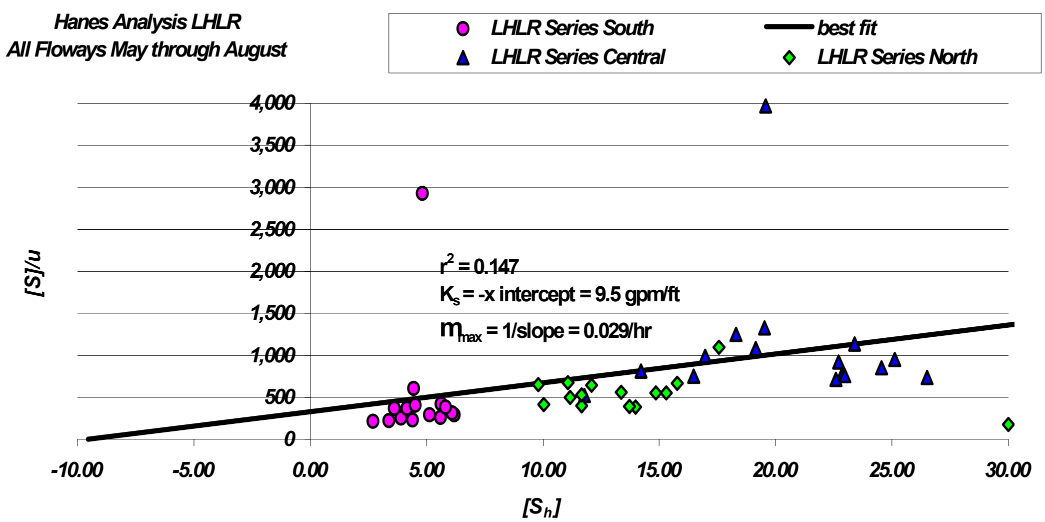


Figure A2-9: Hanes plot LHLR all floways May through August

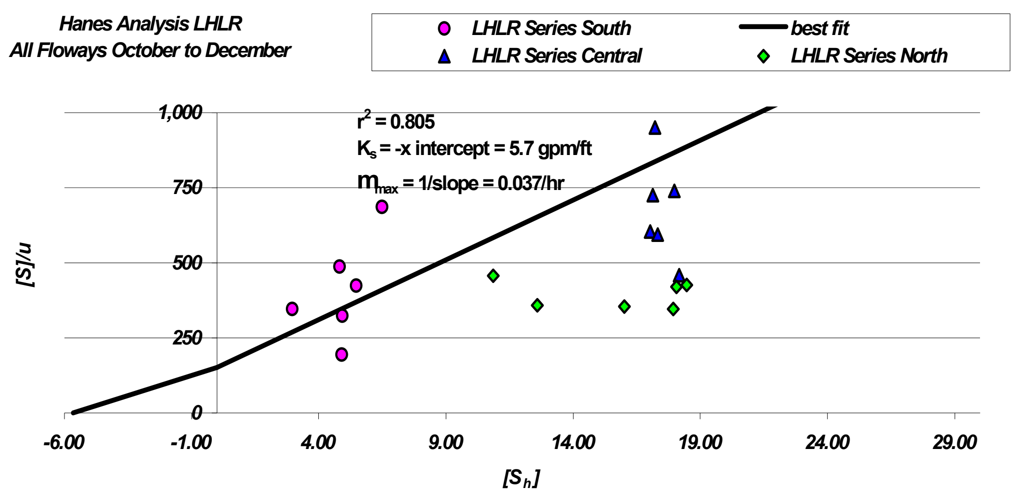


Figure A2-10: Hanes plot LHLR all floways October to December

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:

$$\mathbf{P' = \mathit{a}(14.4pD_s r_c K_s)/\mathit{V}} \qquad \textbf{Equation 12}$$

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 m_{max}, therefore it is reasonable to express the equation as:

$$\mathbf{P' = \mathit{a}(14.4pD_s r_c K_s)/m_{max.}} \qquad \textbf{Equation 13}$$

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

$$\mathbf{m = m_{max.}\ [P'/(P'+1)]S/\ K_s} \qquad \textbf{Equation 14}$$

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:

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

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 m 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 mM as PO_4, or about 3 µg/L as PO_4, or just less than 1 µg/L 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 m_{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:

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

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

$\mathbf{S_{pi}}$ = 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 A-3 and Figure A2-11. The parameter set which resulted in the best projection (lowest standard error=40.61 µg/L) was $\mathbf{m_{max}}$ = 0.04/hr, **K_{sp}** = 37 µg/L, **K_{hp}** = 9.3 gpm/ft, **T_{opt}** = 29.9 ^{o}C and **Q** = 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 A2-12 and A2-13.

Table A2-3: ATSDEM Projection effluent total phosphorus Central Floway

$Z_{0\ dry}$-g	1390
Q	1.10
T_{opt} ^{o}C	29.9
K_{sp} ppb	37
K_{sh} gpm/ft	9.30
m_{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.

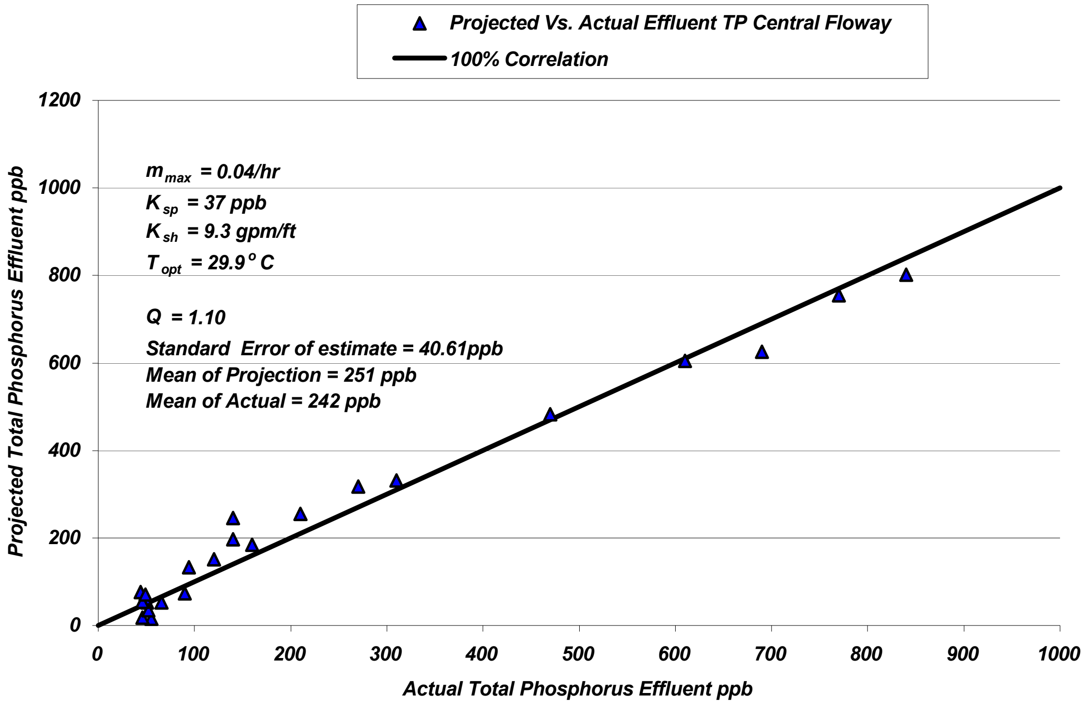


Figure A2-11: Actual Vs. ATSDEM Projected total phosphorus effluent concentration Central Floway

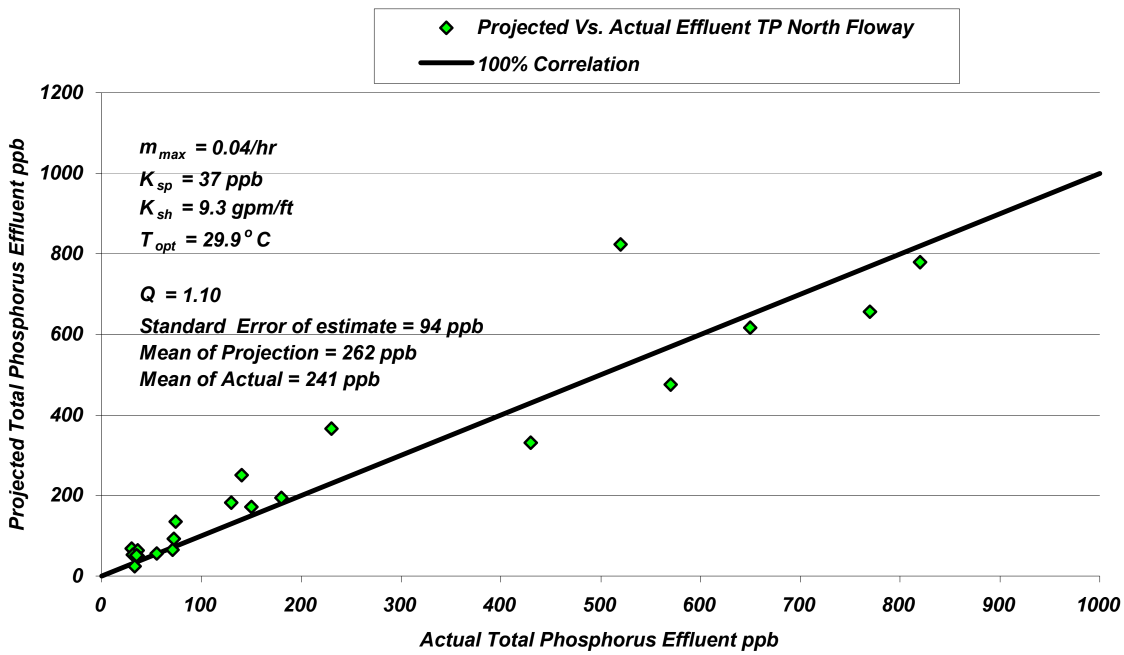


Figure A2-12: Actual Vs. ATSDEM Projected total phosphorus effluent concentration North Floway

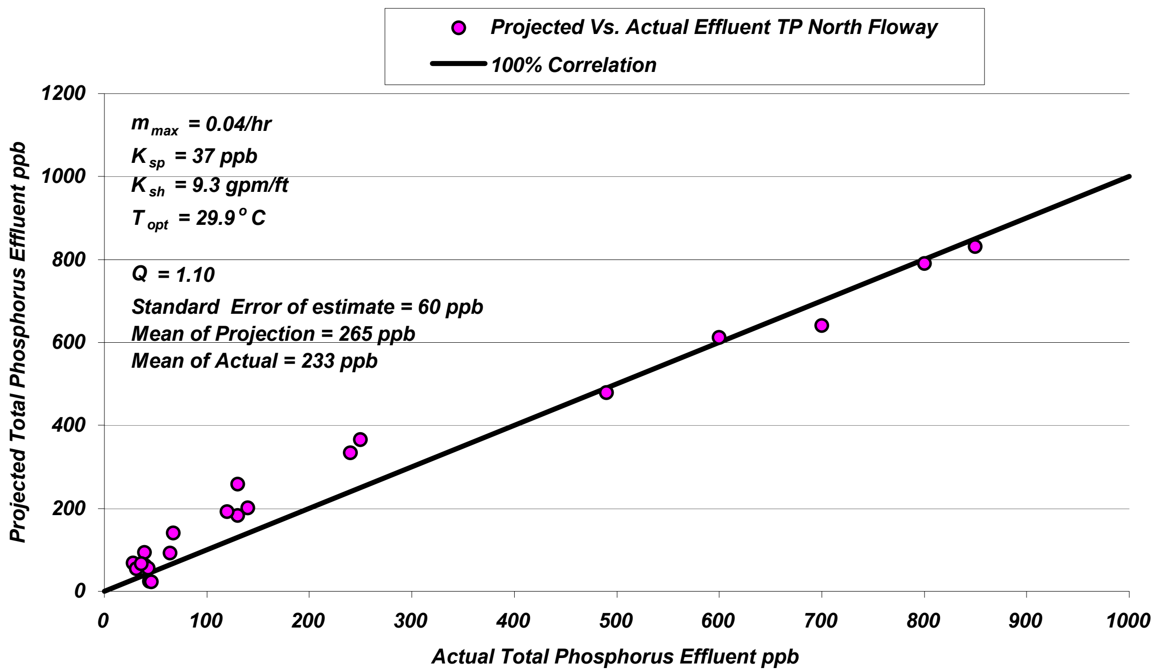


Figure A2-13: Actual Vs. ATSDEM Projected total phosphorus effluent concentration South Floway

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 EXCEL spreadsheet model is often 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, and the engineer includes sufficient contingency provisions to allow operational flexibility. 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, as mentioned in the previous section. The modeling includes assumptions that the system is harvested effectively and completely, with biomass removal complete, and that the standing biomass is sustained at a density that prevents senescence or excessive necrosis. It has been observed that incomplete or too infrequent harvesting can interfere with performance. Harvesting at improper frequencies can also result in excessive densities and attendant poor performance. The general operational strategy is to maintain a consistent biomass range on the ATS™ at all times, and the modeling is based on the presumption that this is done. Senescent algae resulting from improper harvesting strategy 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 successive 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 about a 14 days cycle. ATSDEM projections are based upon a composite mean condition for the entire floway. For example a mean 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.

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

Equation 17

Where **m** is the days since harvest, and **n** is the days between harvests. While setting the optimal value of Z_{ave} will ultimately be by the operator, it may be expected to be higher in warmer months, perhaps over 160 dry-g/m^2, while in the cooler months it may be difficult to establish a crop over 75 dry-g/m^2.

It is recognized that any one section of the ATS™ may be providing better or less treatment than the model projection, but as a mean, 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 flow 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:

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

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 nearly zero to 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:

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

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

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

Therefore:

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

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

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

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 A2-14.

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 (dS_p/dt) may be expressed as:

$$dS_p/dt = S_t(dZ/dt)/q_t \qquad \textbf{Equation 24}$$

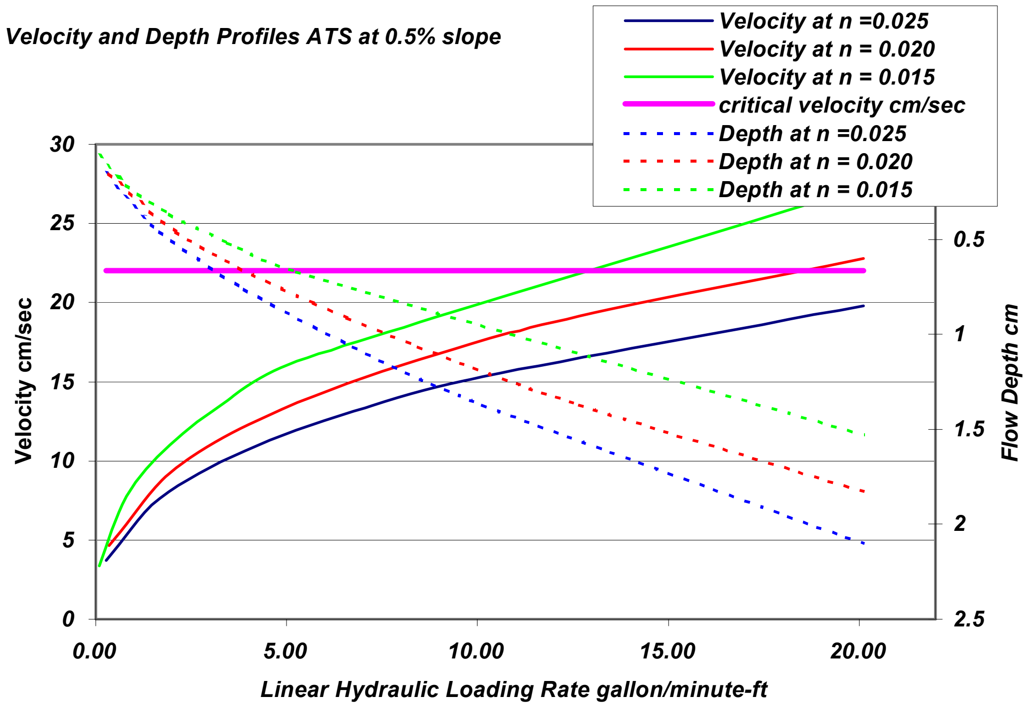
Where q_t=control volume over time increment

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

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

These relationships hold for a relatively short time sequence when $S_{t0} \sim S_{t1}$, 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 m_{max} values. The Manning relationship is incorporated into the model to allow estimation of Velocity and mean flow depth.

The example used for the model run is for a proposed 300 ft long ATS™ system located in the Lake Okeechobee Watershed with a flow of 25 MGD, a design LHLR of 20 gallons/minute-ft, requiring a width of 868 feet and a process area of 5.98 acres. At an incoming total phosphorus concentration of 150 µg/L, and evaluating the proposed facility over four quarters, using water temperature from existing field data[x], the annual total phosphorus removal, as noted in Table A2-4, is 3,149 lbs/year, with an annual harvest of 4,140 wet tons, resulting in the generation of 561 cy of finished compost. A typical model summary printout is noted for Quarter 2 in Figure A2-14.



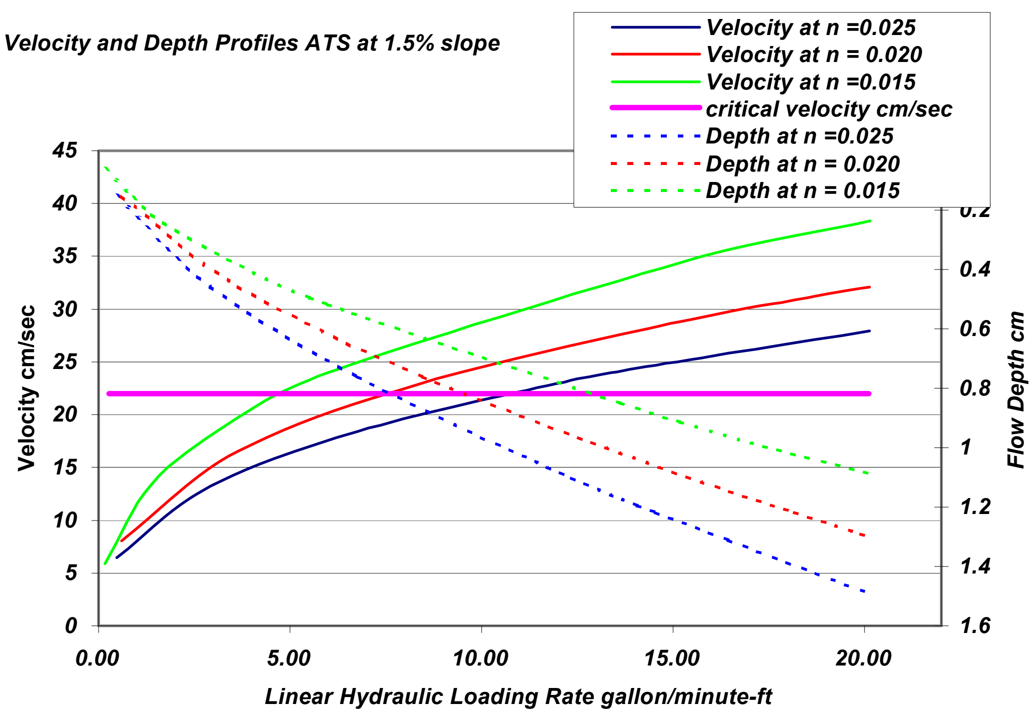


Figure A2-14: Velocity, LHLR and depth relationships as determined from Manning Equation

Table A2-4: ATSDEM summary 25 MGD Lake Okeechobee Watershed ATS™

Conditions:	
Flow MGD	25
Average Flow Velocity fps	0.93
Average Flow Depth inches	0.58
Average Flow-through time minutes	324
Influent TP	150
ATS length ft	300
ATS Headwall Width ft	868
ATS Acreage	5.98
ATS slope	1.00%

Parameter	Q1	Q2	Q3	Q4	Total Annual
Effluent Total Phosphorus ppb	133	109	74	118	109
Total Phosphorus Areal Removal Rate lb/acre-yr	212	524	970	401	527
Total Phosphorus Removed lb	317	783	1,450	599	3,149
Wet Harvest tons	532	83	2,510	1,015	4,140
Compost tons	33	83	157	63	337
Compost CY	55	139	261	106	561

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
0.01	0.02	0.005981	0.005981	20	0.045	1.280	0.05	0.93	0.93

Panel B Process Conditions

Water T °C	Optimal T °C	Q	K_{sp} as ppb TP	K_{sh} as LHLR gpm/ft	m_{max} 1/hr	S_o ppb Total P	Harvest Cycle days	Z_{ave} dry-g/m^2	Z_0 dry-g/m^2	S^*_p Total Phosphorus ppb
27.44	29.9	1.10	37	9.3	0.04	150	7	105.74	10.00	30

Panel C Performance

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-year	Areal Removal Rate TP g/m2-yr	Areal Removal Rate TP lb/acre-yr	Average Production dry-g/m^2-day	Area per time sequence m^2
1	1.280	109	324	27%	300	214	1909.18	59	524.07	27.39	0.086

Panel D System Design

Total Flow mgd	Floway Width ft	Floway Area acres	Total P removed lb/period	Moisture % wet harvest	Moisture % compost	Period Wet Harvest tons	Period Dry Harvest tons	Period Compost Production wet tons	Performance Period days	m_{ave} 1/hr
25	868	5.98	783.38	5%	40%	1,332	67	83	91.25	0.0168

Note: Inputs in Blue Print

Figure A2-15: Conceptual Design Parameter and Summary Worksheet Lake Okeechobee Watershed Quarter 2 ATS™ 25 MGD

[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

[x] White, J.R., K.R. Reddy, and T.A. DeBusk. 2001. Preliminary design of vegetation modifications and pilot development of sediment management protocols for the City of Orlando's Easterly Wetland's treatment system. A proposal for the City of Orlando.