S-154 Pilot
Single Stage Algal Turf Scrubber® (ATS™)
Final Report

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Prepared by:

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Prepared for:

South Florida Water Management District

Under Contract No. C-13933

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DEPARTMENT OF ENVIRONMENTAL PROTECTION
FLORIDA

FLORIDA DEPARTMENT OF AGRICULTURE
AND CONSUMER SERVICES
CHARLES H BRONSON
COMMISSIONER

Table of Contents

ABBREVIATIONS

°C	Degrees Celsius
µg/cm	micrograms per centimeter
µg/L	micrograms per liter
Ac	Acre
AFDW	Ash-free Dry Weight
ATSDEM	ATS™ Design Model
ATS™	Algal Turf Scrubber®
ATT	Advanced Treatment Technologies
BMP	Best Management Practices
ca	calcium
cf/d	cubic feet per day
cfs	cubic feet per second
cm	centimeter
cm/d	centimeters per day
$CO_3^=$	carbonate
CTSS	Chemical Treatment Solids Separation
CU	color unit
cy	cubic yard
DMSTA	Dynamic Model for STA
DO	dissolved oxygen
dry g/m^2/day	dry grams per meter squared per day
DW	dry weight
EAA	Everglades Agricultural Area
EFA	Everglades Forever Act
EPA	Everglades Protection Area
ESTA	Emergent Stormwater Treatment Areas
ET	evapotranspiration
FDEP	Florida Department of Environmental Protection
FEB	flow equalization basin
FIU	Florida International University
ft	feet
ft2	square feet
gpm	gallons per minute
gpm/lf	gallons per minute per linear feet
GPP	Gross Primary Production
ha	hectare
HCO_3^-	bicarbonate
HDPE	high-density polyethylene
HLR	Hydraulic Loading Rate
HRT	hydraulic residence time
HYADEM	Hyacinth Design Model
IFAS	Institute of Food and Agricultural Sciences
in	inch
kwh	kilowatt-hour
L	liter
LHLR	Linear Hydraulic Loading Rate
LOW	Lake Okeechobee Watershed
LR	limerock
m	meter

m/d	meters per day
MAPS	Managed Aquatic Plant Systems
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mgd	million gallons per day
NA	not available
NPP	Net Primary Production
NTU	Nephelometric Turbidity Unit
O&M	operation and maintenance
OH^-	hydroxide
P	phosphorus
POR	Period of Record
ppb	parts per billion
PSTAs	Periphyton-based Stormwater Treatment Areas
PWC	present worth cost
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
SAV	Submerged Aquatic Vegetation
SAV/LR	submerged aquatic vegetation/limerock
sf	square feet
SFWMD	South Florida Water Management District
STA	Stormwater Treatment Area
STSOC	Supplemental Technology Standards of Comparison
TDP	total dissolved phosphorus
TDS	total dissolved solids
TKN	total Kjeldahl nitrogen
TMDL	Total Maximum Daily Load
TOC	total organic carbon
TOP	total organic phosphorus
TP	total phosphorus
TPP	total particulate phosphorus
TSS	total suspended solids
USACOE	U.S. Army Corps of Engineers
WCA	Water Conservation Area
WHS™	Water Hyacinth Scrubber
WY	Water Year

EXECUTIVE SUMMARY

In January, 2003 the S-154 Managed Aquatic Plant System (MAPS) Pilot “S-154 Pilot” was established with the intent of documenting phosphorus treatment performance of a two-stage MAPS system with a Water Hyacinth Scrubber (WHS™) serving as a receiving unit, and an Algal Turf Scrubber® (ATS™) as the polishing unit.

While the S-154 Pilot’s primary objective was minimizing outflow phosphorus concentrations, Total Maximum Daily Load (TMDL) mandates in the Lake Okeechobee Watershed (LOW) have highlighted the need to optimize pollutant load removal at the lowest possible treatment costs. With successful performance of the two-stage MAPS S-154 Pilot, and documented ATS™ phosphorus removal rates of up to approximately 450 g/m^2-yr or 4,000 lbs/acre-yr in single stage applications, a pilot investigation of the ATS™ technology as a single stage treatment system was proposed. The objectives for the single stage ATS™ units were to (i) quantify performance while optimizing for phosphorus load removal, (ii) refine design conditions for a full-scale ATS™ unit in the LOW and (iii) allow for accurate engineering estimates of full-scale treatment system costs in the LOW.

Three single stage ATS™ units were isolated from the existing S-154 ATS™ facilities. ATS™ floway length was limited to 300 feet based on existing facilities. The operational period of record (POR) was from May 11, 2004 to November 29, 2004 for the South and North floways, and to December 5, 2004 for the Central floway.

The three independent floways received varying hydraulic loads to allow assessment of optimal loading and corresponding phosphorus removal rates. The South floway received a mean hydraulic loading rate (HLR) of 92 cm/day and a Linear Hydraulic Loading Rate (LHLR) of 4.7 gallon/minute-ft. The North floway received a HLR of 157 cm/day and a LHLR of 8.5 gallon/minute-ft. The Central floway, received a HLR of 368 cm/day and a LHLR of 18.8 gallon/minute-ft. Optimizing the ATS™ floway for pollutant uptake by varying hydraulic loads was designed to allow for assessment of phosphorus treatment costs for the stated objective of load removal.

The South floway, operated at the lowest LHLR removed total phosphorus at the mean rate of 25 g/m^2-yr (24.08% removal) from a mean phosphorus loading rate of 109 g/m^2-yr. The mean influent total phosphorus concentration to the South floway was 336 ppb, with the mean effluent total phosphorus concentration at 250 ppb.

The North floway operated at mid-level LHLR removed total phosphorus at the mean rate 47 g/m^2-yr (24.85% removal) from a mean phosphorus loading rate of 157 g/m^2-yr. The mean influent total phosphorus concentration to the North floway was 336 ppb, with the mean effluent total phosphorus concentration at 249 ppb.

The Central floway operated at the highest LHLR removed total phosphorus at the mean rate 92 g/m^2-yr (23.08% removal) from a mean phosphorus loading rate of 397 g/m^2-yr. The mean influent total phosphorus concentration to the Central floway was 333 ppb, with the mean effluent total phosphorus concentration at 258 ppb.

Illustrated in Figure ES-1 are the phosphorus areal removal rates for the three single stage S-154 ATS™ floways. Included for comparison is the areal removal rate for the Everglades Stormwater Treatment Areas “STAs” for Water Year (WY) 2004. While the design objectives are different for the Everglades STAs, treatment wetlands are typically designed for a HLR of 5 cm/d or less, hence areal removal rates for treatment wetlands in the Lake Okeechobee Watershed are not expected to deviate significantly from that achieved with the Everglades STAs.

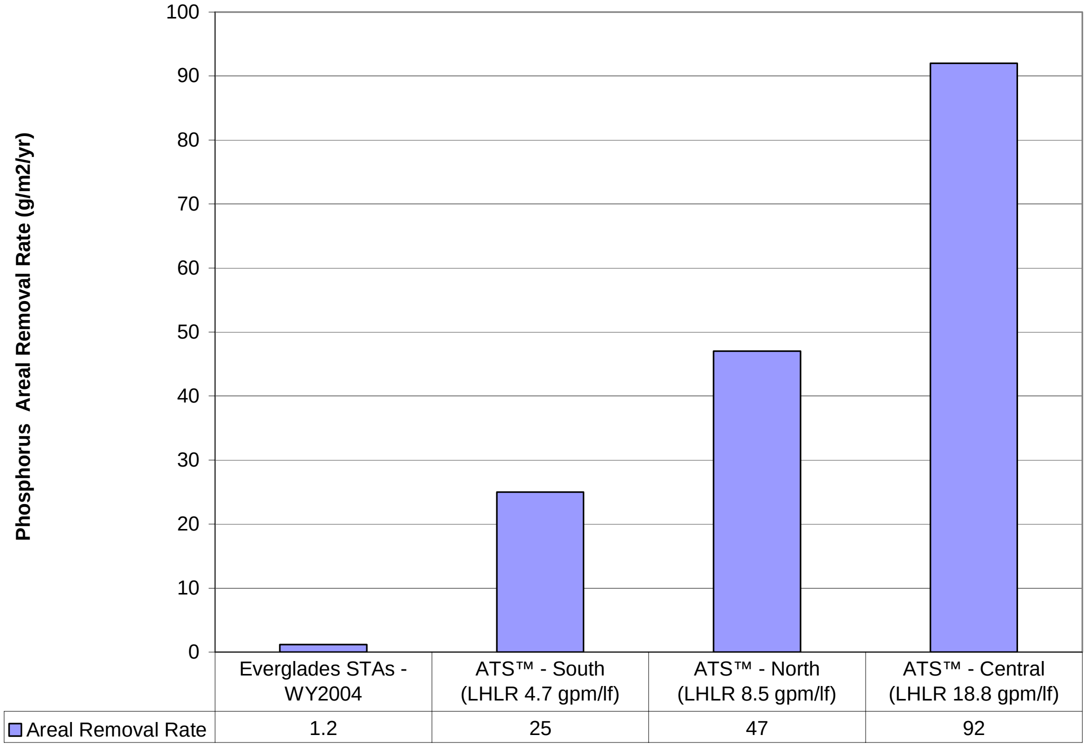


Figure ES-1: Phosphorus areal removal rates for S-154 ATS™ treatment units and Everglades Stormwater Treatment Areas (WY2004)

The South floway removed total nitrogen at the mean rate of 181 g/m^2-yr (28.96 % removal) from a mean total nitrogen loading rate at 624 g/m^2-yr. The mean influent total nitrogen concentrations to the South floway were 1.85 mg/l, with the mean effluent total nitrogen concentration at 1.27 ppb.

The North floway removed total nitrogen at the mean rate of 332 g/m^2-yr (29.66% removal) from a mean loading rate of 1,120 g/m^2-yr. The mean influent total nitrogen concentration to the North floway was 1.85 mg/l, with the mean effluent total nitrogen concentration at 1.30 ppb.

The Central floway removed total nitrogen at the mean rate of 722 g/m^2-yr (29.73% removal) from a mean loading rate of 2,428 g/m^2-yr. The mean influent total nitrogen concentration to the Central floway was 1.85 mg/l, with the mean effluent total nitrogen concentration at 1.32 ppb.

Illustrated in Figure ES-2 are the nitrogen areal removal rates for the three single stage S-154 ATS™ floways.

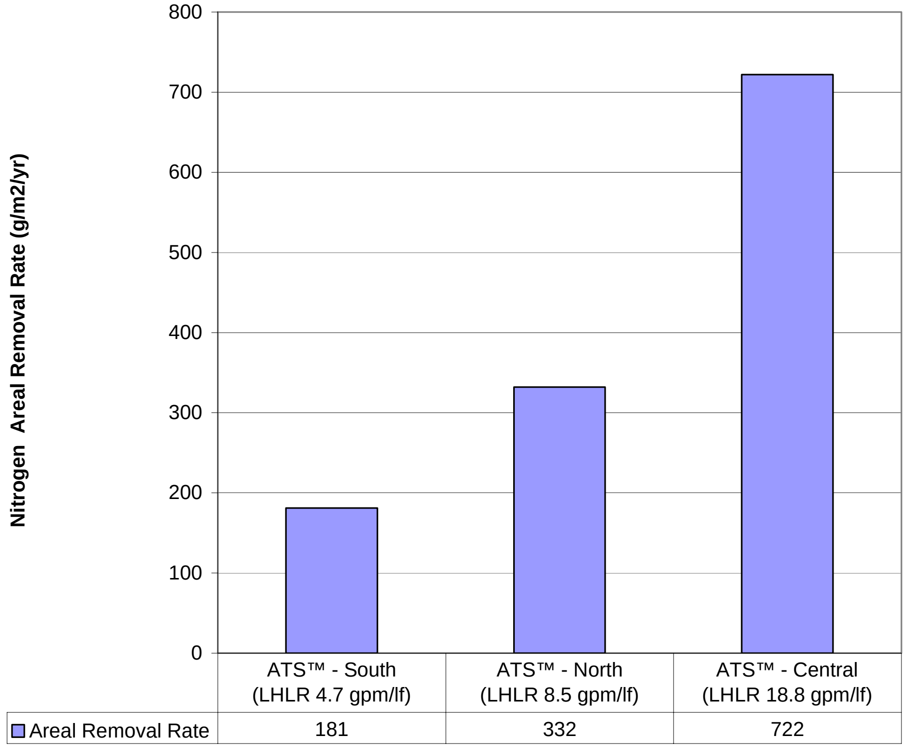


Figure ES-2: Nitrogen areal removal rates for S-154 ATS™ treatment units.

Optimized for pollutant load removal, the Algal Turf Scrubber® technology demonstrated a 368% increase in phosphorus load reduction, and a 399% increase in nitrogen load reduction with increased hydraulic loading to the system. These values were consistent with model projections, and confirmed the ATS™ capacity to achieve enhanced pollutant load reduction within relatively low concentration surface water runoff.

Increased pollutant load reduction capacities result in reduced treatment facility size and are projected to result in reduced pollutant treatment costs for Total Maximum Daily Load (TMDL) applications. Analysis of treatment costs and biomass markets are provided within a separate report under Contract C-13933.

SECTION 1. INTRODUCTION

SUMMARY OF TECHNICAL FOUNDATION FOR ATS™

Periphytic and epiphytic algal communities have for some time been recognized as ecologically important, both for their contributions as primary producers, and for their modulating influences regarding energy and nutrient flux within low nutrient systems. In his classic study on Florida's Silver River discusses this role of the epiphytes (aufwuchs) that develop upon the submerged vascular plant *Vallisneria sp.* (eel grass) in stabilizing and distributing the energy and materials within this freshwater spring system (Odum, 1955).

These types of algal communities also serve a critical role in nutrient management within the oligotrophic Everglades Ecosystems. Browder et al. note that "*the assemblage of microalgae that live in shallow, submerged substrates, ---referred collectively as periphyton, aufwuchs, or the algae mat*", is the most widely distributed plant community in the Florida Everglades. This mat community is called "Algal Turf" (Adey and Loveland, 1998). It is recognized that the use of "plant community" to describe algae may not be taxonomically correct, but it does correctly identify the community as being composed primarily of photoautotrophic organisms. Two principal periphytic communities within the oligotrophic regions of the Everglades are identified—a calcareous periphyton dominated by the low nutrient tolerant blue-green algae (bacteria) *Schizothrix calacicola* and a soft water low nutrient tolerant community dominated by Desmids and filamentous green algae (Browder et al., 1994).

The ability of certain algae species to flourish in low nutrient levels has drawn the attention and investments from the South Florida Water Management District (District) and the U.S. Army Corps of Engineers (USACOE), as well as others assigned the responsibility of implementing the Comprehensive Everglades Restoration Program (USACOE, 1997; CH2MHill, 2003). The possibility of exploiting these algal communities for nutrient management was apparently first suggested to the USACOE by researchers at Florida International University—FIU (Doren and Jones, 1996). Both the District and USACOE have since invested in the development of an algal- based technology called a Periphyton Based Stormwater Treatment Area or PSTA, which relies upon expansive areas of calcareous substrate over which large quantities of water can be retained and treated by periphytic communities dominated by algal species tolerant of low nutrient conditions. Studies indicate considerable effectiveness of the PSTA to achieve low levels of total phosphorus (USACOE, 2003; CH2MHill, 2003).

The PSTA approach relies largely upon the accumulation of phosphorus laden, calcareous depositions, and is not algal production oriented per se, when compared to the ATS™ approach, although sustenance of a viable algal mat is noted as an important P storage compartment. Because optimization of algal productivity is not a priority with PSTA, there is little discussion within the associated literature related to disruption of cell boundary layer or the attenuation of diffusion impediments as a means of enhancing nutrient uptake. However, increases in flow-through velocities appear to enhance PSTA performance (Kadlec and Walker, 2003). The velocities reviewed however were low, typically 0.5 cm/sec or less, when compared to ATS™ systems, where surge velocities can exceed 50 cm/sec. A detailed review of the PSTA technology by Kadlec and Walker provides specific findings from a number of studies, and offers a convenient chronology of development.

While the work on PSTA clearly includes statements that harvesting of the sediment accumulations or the associated periphytic algae is not within the operational plan for PSTA, there are references from others regarding the need for harvesting (CH2M Hill, 2003; Thomas et al., 2002). Within this work, the FIU scientists elaborate upon various "harvesting" regimens, and clearly indicate that consideration and implementation of harvesting (referenced often as scrape-down and removal of the calcareous deposits) needs to be seriously considered for incorporation into the PSTA protocol.

Additionally, a peer review of the District's assessment of the PSTA technology includes a notification that:

"The [PSTA] design assumes no harvesting of biomass or sediments. Handling of biosolids is a management and technical challenge, and therefore needs further study. The treatment operation is expected to continue for 50 years. The accumulation of sediments are very likely to release the stored P, especially during high flow periods." (PB Water, 2002)

This issue of harvesting remains confused within the scientific community involved in PSTA, Emergent Stormwater Treatment Areas (ESTA) and Submerged Aquatic Vegetation Stormwater Treatment Areas (SAV) review. Nonetheless CH2MHill as noted, did not consider PSTA harvesting when they completed a Supplemental Technology Standard of Comparison (STSOC) analysis, nor was harvesting included in SAV or ESTA STSOC evaluations (CH2Mhill, 2003). In spite of this, a recent review by the District includes recognition that management of accumulated sediments within these type of expansive systems will be required, although no detailed analysis of potential costs are included (Goforth, 2005).

The evolution of the ATS™ found genesis in work by researchers with the Smithsonian Institute working on marine systems. The role of periphytic and epiphytic algae in the maintenance of low nutrient levels within coral reef systems, and the ability of these organisms to sustain high levels of productivity under oligotrophic conditions, when supported by the energy associated with tidal movement and oscillatory waves was recognized. This dynamic was later elaborated upon in developing the Algal Turf Scrubber® (Adey and Goertmiller, 1987; Adey and Hackney, 1989; Adey, 1998).

The influence of boundary layer disruption upon algal productivity in low nutrient seawater through increased flow velocity was examined within the laboratory. Significant increases in productivity of marine periphytic algae as the flow velocity increased from zero cm/sec to over 22 cm/sec was noted. The velocity at which improved production was no longer aided by velocity varied with the species. For all species studied, velocities over 22 cm/sec (about 0.75 ft/sec) did not solicit improved production. However, oscillatory waves did further stimulate higher production when compared to steady flow (Carpenter et al., 1991).

From the early works by Adey and his colleagues evolved the concept of a structured approach to promote the growth of periphytic algae in association with treating waters attendant with mesocosms, including coral reef mesocosms. This structured approach was patented as an Algal Turf Scrubber® (ATS™) by Adey in subsequent U.S. Patents: 4,333,263 –1982: 4,966,096-1990; 5,097,795—1992: and 5,851,398—1997. The central theme within these patents is the cultivation of periphytic algae communities or "Algal Turf" upon a constructed substrate, typically sloped, and the surging or pulsing of water across the substrate, with the periodic harvesting of accumulated biomass. In addition, the latest patent includes the purposeful management of the system to solicit precipitation of phosphorus upon or within the algal cell walls.

As noted, early work on the ATS™ concept was applied to very low nutrient conditions related to coral reef systems, and the effectiveness of the ATS™ concept helped facilitate successful cultivation of corals within aquaria, and larger cultivation tanks (Luckett et al., 1996). Considering the potential of the ATS™ to provide wholesale removal of nutrient pollutants from wastewaters, and polluted freshwater as well as saltwater surface waters, Adey provided oversight to two ATS™ demonstrations—the first being in Patterson, California the second in the Everglades Agricultural Area (EAA) in South Florida (Adey et al. 1993; Craggs et al. 1996). Subsequently, the ATS™ was applied in two recirculating Fish Aquaculture facilities—one in Fall River, Texas, the other in Okeechobee County, Florida. The latter facility was designed and operated by HydroMentia, Inc. for several years. The flows within this facility approached 30 MGD of recycled flow. The ATS™ unit removed a mean of 9.5 lb-P/acre-day (389 g-P/m^2-yr) within this facility with algal productivity above20 dry-g/m^2-day (Stewart, 2000). Because this facility included recirculation of water from a high intensity fish cultivation operation, the nutrient levels were very high. Low nutrient ATS™ systems are generally more germane to the application in the Lake Okeechobee Watershed (LOW) as well as the Everglades Protection Area (EPA).

POLLUTANT LOAD OPTIMIZATION FOR S-154 PILOT

The S-154 Managed Aquatic Plant System (MAPS) Pilot “S-154 Pilot” was established in January, 2003 with the intent of monitoring and documenting performance of a combined Water Hyacinth Scrubber (WHS™) and Algal Turf Scrubber® (ATS™) system. The project layout involved these two process stages, with the WHS™ as the receiving unit, and the ATS™ as the final polishing unit. For over 19 months, this two-stage system provided consistent performance with overall reduction of total phosphorus by 73.1%. The two-stage system MAPS system was developed with a primary objective of minimizing outflow phosphorus concentration.

While the S-154 Pilot’s primary objective was minimizing outflow phosphorus concentrations, TMDL mandates in the Lake Okeechobee Watershed have highlighted the need to optimize pollutant load removal. With documented ATS™ phosphorus removal rates of up to 4000 lbs/acre/year, a pilot investigation of the ATS™ technology as a single stage treatment system was proposed.

INTERNAL RECYCLING AND LINEAR HYDRAULIC LOADING RATE

During the first nine-month period (Q1-Q3) of the two-stage MAPS S-154 Pilot, recycling of ATS™ effluent was included as part of the operational strategy of the second stage ATS™ unit. The intent of recycling was to sustain a high hydraulic loading rate or HLR and a high linear hydraulic loading rate or LHLR (the flow rate per width of ATS™), which has been shown to be important to the promotion of algal production. After reviewing the algae production rate associated with this recycled flow it was determined that both the high pH and high water temperature had a deleterious impact upon algae production. Consequently, in November 2003 it was decided to eliminate recycling to the ATS™. While this resulted in a reduction of LHLR, there was noted a general improvement in algal production.

Recognizing the importance of LHLR to the maintenance of high removal rates and algal production, HydroMentia recommended that three individual ATS™ floways be isolated to serve as single-stage ATS™ prototypes. The operational strategy was to develop variations in LHLR across these floways, while introducing feedwater directly from the source (L-62 Canal), thereby allowing optimization of the ATS™ as a single stage process in terms of total phosphorus areal removal rates. A contract extension for the S-154 Pilot was granted in late 2003 which facilitated the development of the single stage ATS™ units.

SINGLE STAGE ATS™ FLOWAYS

Individual ATS™ floways were designed to receive three levels of hydraulic flow, resulting in different nutrient loading rates. For continuity, the floways were designated South, Central, and North. Flows were established such that the South floway received about 5 gallons per minute for each foot of the five foot ATS™ width, or 25 gpm; the Central floway received about 20 gallons per minute for each foot of the five foot ATS™ width, or 100 gpm; and the North floway received about 10 gallons per minute for each foot of the five foot ATS™ width, or 50 gpm. As the three floways received flow from the same source, were operated at the same slope, and experienced the same external environmental conditions, an ideal situation was established to review the impacts of the one factor that differed among the floways--that being LHLR. Flow to all floways was delivered via a surger device, so pulsing of flows could be maintained.

The influent water quality was monitored through existing influent sampling protocol for the S-154 Pilot

- as the two pumping systems withdrew water from the same source, at the same position (mid-depth, mid-canal). The two intake structures were positioned contiguous to one another. Effluent from each single stage floway was sampled continuously through a time sequenced composite sampler using three Sigma 900 refrigerated automatic samplers.

The independent single-stage ATS™ floways were installed during the spring of 2004, and placed into full operations on May 11, 2004. The three single-stage floways were installed within the boundaries of the southern ATS™ unit constructed as part of the S-154 Pilot. The northern unit was used for continued operation of the two-stage MAPS Pilot. The general layout and flow dynamics of the single-stage floways is noted within Figures 1-1 through 1-3.

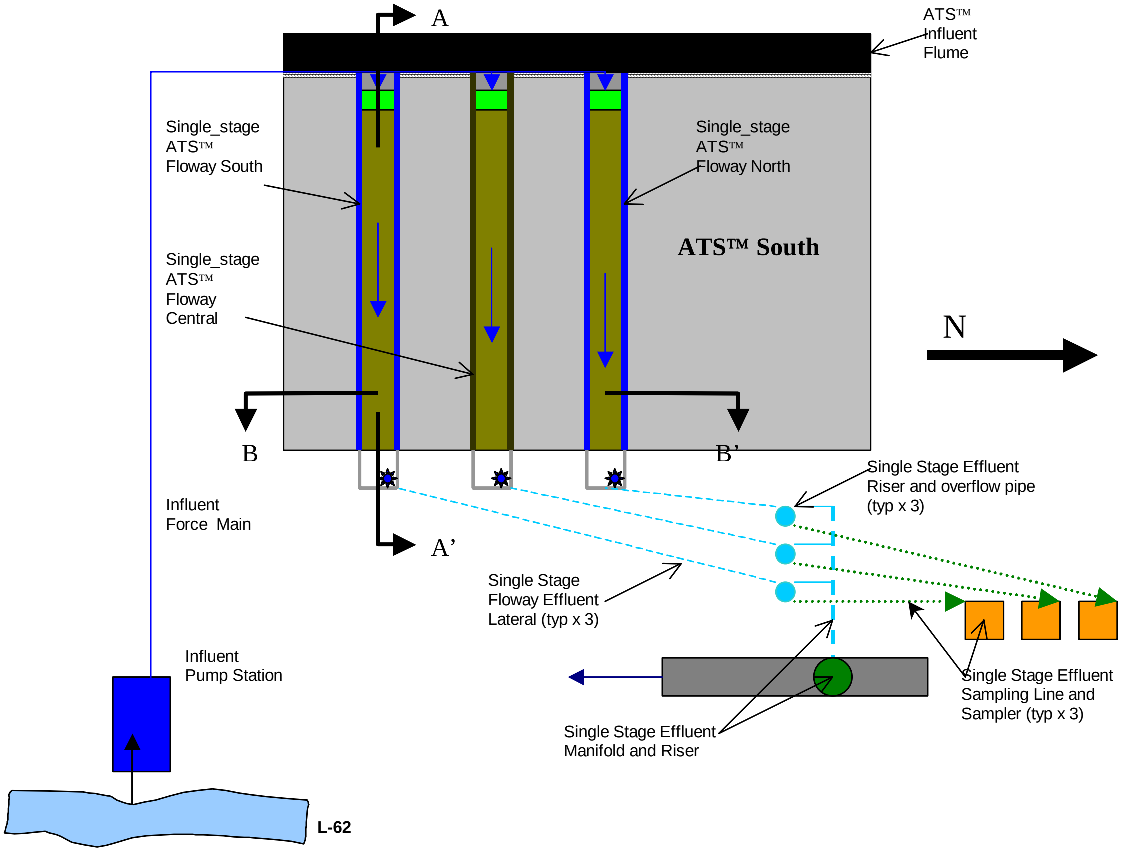


Figure 1-1: General Plan and flow schematic single stage ATS™ floways: drawing not to scale

Each floway was established at a width of five feet, and was accommodated by existing flow surgers. Flow was introduced directly to the surger via a force main serviced by a self-priming Gorman-Rupp pump at the L-62 canal. The pump has a delivery capacity of about 200 gpm. The flow was monitored using a propeller type flow meter associated with each floway. The meters provided instantaneous and totalized flow.

Of the three floways, the edges of the Central floway were established by extrusion welding a flap of 40 mil HDPE continuously down the floway length (see Figure 1-3), thereby preventing leakage of water into or out of the floway. The South and North floways' edges were isolated using flexible discharge hose, which was filled with water to sustain a solid border. Very minimal flow was noted to escape from these floways, and they were kept from cross contamination by the solid barrier of the Central floway.

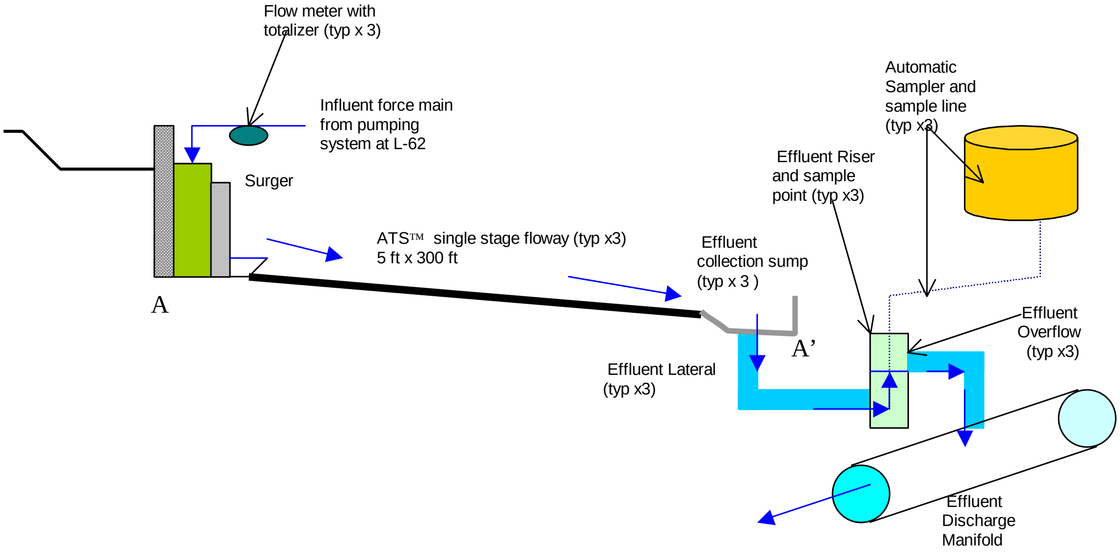


Figure 1-2: Section A-A' single stage ATS™ floway: drawing not to scale

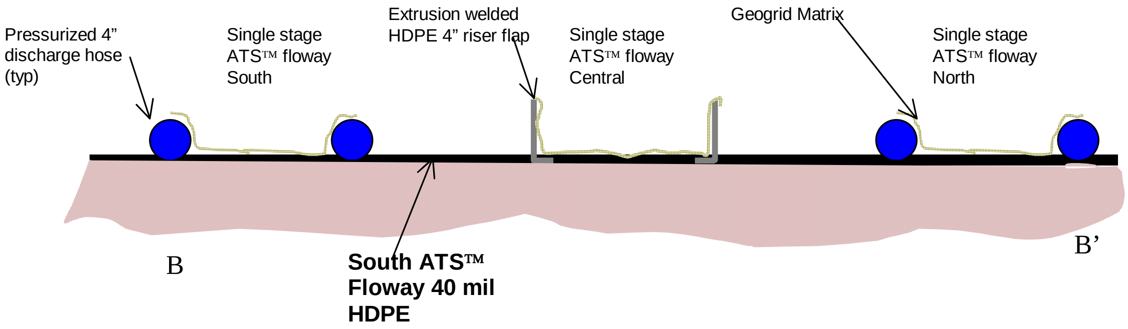


Figure 1-3: Section B-B' single stage ATS™ floways: drawing not to scale

The main flow from the two-stage system was transferred to the North ATS™ so there was no chance of cross- contamination as this site is separated from the single stage floways by a berm. Only one floway was isolated using the welded HDPE because of the required additional time for installation and the higher costs.

Flow from each floway was collected in an isolated sump and conveyed via an 8" lateral to a 12" riser, as shown in Figures 1-1 and 1-2. The riser serves to isolate the flows and to accommodate the sampler intake. An overflow allows the effluent to fall by gravity into a common effluent discharge manifold, which in turn discharges into the 24" HDPE outflow pipe; from which treated flows are delivered to the L-62 canal. The riser overflow ensures each floway is hydraulically isolated.

Sampling was done using three (3) Sigma 900 refrigerated units, which were maintained within the air-conditioned operations effluent trailer. Sampling is done continually on a time-sequenced basis. Field measurements for pH, DO, conductivity and temperature were taken twice daily.

Harvesting of the floways was done by hand, with the collection of scraped algae being weighed on a State certified platform scale. During harvest, the flow was discontinued. Flow was returned after the completion of harvesting. Several grab samples were taken from the harvested biomass from each floway, and these composited for further analysis. After determining the moisture content of the harvest sample, the composited dry samples were delivered to MidWest laboratories for chemical analysis. Harvest frequency was determined in the field to optimize crop health and production and was typically conducted weekly during warmer periods, and bi-weekly during the cool season.

SECTION 2. WATER QUALITY AND TREATMENT PERFORMANCE

MONITORING PERIOD / PERIOD OF RECORD (POR)

The period of record (POR) applicable to the analytical water quality data and the attendant performance assessment noted in Section 4 is from May 11, 2004 to November 29, 2004 for the South and North floways, and to December 5, 2004 for the Central floway. On September 3-4, 2004 Hurricane Frances hit the facility with reported sustained winds at 95 mph. The facility was not damaged, but over 7" (rain gauge maximum was 7") of rain fell within a 24-hour period, and power was lost sometime during the hurricane strike—probably late on the September 3rd or early September 4th. The power returned on September 14th at 3:00 PM, and the system was placed back into operation. On September 27th Hurricane Jeanne hit the site with similar winds and rainfall, and power was again lost until October 3, 2004, at which time the system was brought back on-line.

Samples taken by the auto-sampler from August 30 until the power outage of September 3-4 were not retrieved until September 9, 2004 by U.S. Biosystems. As these samples had not been refrigerated since the power outage, the results must be considered outside the QA/QC requirements. They are helpful however in developing an assessment of the impacts of severe weather upon system performance and recovery. Within Section 4, data from August 30, 2004 through October 18, 2004 are used to assess the impact of Hurricane Frances upon the system.

For establishing system behavior under stable operational conditions, data collected during the period of hurricane impact and subsequent start-up are not included. This period includes the sampling period beginning August 30, 2004 through the period ending October 18, 2004.

Considering the 28 days of down time due to planned or accidental shut downs, as listed below, it encompassed 175 days for the South and North floways, and 181 days for the Central floway. During this period the system experienced the following shut downs:

- July 6 through 9, 2004 Pumping was terminated because of herbicide application within L-62 by the District.
- August 11 and 12, 2004 Pumping was terminated because of herbicide application within L-62 by the District.
- August 25 and 26, 2004 Power loss due to lightening damage to transformer.
- September 3 through September 14, 2004 due to Hurricane Frances
- September 27 through October 3, 2004 due to Hurricane Jeanne.

ANALYSIS OF FLOWS

For the adjusted POR, which includes 139 days, and is exclusive of those days impacted by the two Hurricanes, the South floway, with a total area of 139 m^2, received flows at a mean hydraulic loading rate (HLR)) of 92 cm/day and a Linear Hydraulic Loading Rate (LHLR) of 4.7 gallon/minute-ft. For the adjusted POR, the Central floway, with a total area of 139 m^2, received flows at a mean hydraulic loading rate (HLR) of 368 cm/day and a Linear Hydraulic Loading Rate (LHLR) of 18.8 gallon/minute-ft. For the adjusted POR, the North floway, with a total area of 149 m^2, received flows at a mean hydraulic loading rate (HLR)) of 157 cm/day and a Linear Hydraulic Loading Rate (LHLR) of 8.5 gallon/minute-ft. This floway was diverted slightly to the south to avoid high points in the existing geomembrane; hence the length was extended from 300 to 320 ft, resulting in a higher surface area. Hydraulic loading to the three single stage ATS™ units are provided in Tables 2-1 through 2-3 and Figure 2-1.

Table 2-1: Hydraulic Loading Parameters single-stage ATS™ floway South

	ft or ft^2	m or m^2
Floway length	300	91.5
Floway width	5	1.5
Floway Area	1,500	139

	Operational time days	Hydraulic Load for period gallons	Hydraulic Load average per operational day gallons	Areal Hydraulic loading rate cm/day	Linear Hydraulic Loading Rate gallons/minute-lf
5/17/2004	6	267,635	44,606	121	6.2
5/24/2004	7	307,175	43,882	119	6.1
5/31/2004	7	282,112	40,302	109	5.6
6/7/2004*	7	196,784	28,112	76	3.9
6/14/2004	7	234,645	31,719	86	4.4
6/21/2004	7	222,036	40,468	110	5.6
6/28/2004	7	283,278	19,347	53	2.7
7/5/2004	3	135,426	36,880	100	5.1
7/12/2004	7	110,640	31,944	87	4.4
7/19/2004	7	223,609	34,733	94	4.8
7/26/2004	7	243,134	29,875	81	4.1
8/2/2004	7	209,125	32,537	88	4.5
8/9/2004	7	227,760	25,992	71	3.6
8/16/2004	5	181,945	41,874	114	5.8
8/23/2004	7	209,369	24,263	66	3.4
8/30/2004	5	169,840	33,968	92	4.7
9/9/2004	4.5	137,050	30,456	83	4.2
9/13/2004	Hurricane Frances				
9/20/2004	5.5	151,941	27,626	75	3.8
9/26/2004	6	163,002	27,167	74	3.8
10/4/2004	Hurricane Jeanne				
10/11/2004	7	201,504	28,786	78	4.0
10/18/2004	7	180,947	25,850	70	3.6
10/25/2004	7	275,731	39,390	107	5.5
11/1/2004	7	148,838	21,263	58	3.0
11/8/2004	7	326,566	46,652	127	6.5
11/15/2004	7	248,487	35,498	96	4.9
11/22/2004	7	242,969	34,710	94	4.8
11/29/2004	7	246,728	35,247	96	4.9
TOTAL POR	175	5,828,276	33,304	90	4.6
TOTAL Adjusted POR	139	4,726,197	34,001	92	4.7

*Totalizer not functioning, flows calculated from average instantaneous rate
Adjusted POR excludes shaded area influenced by Hurricanes

Table 2-2: Hydraulic Loading Parameters single-stage ATS™ floway Central

	ft or ft^2	m or m^2
Floway length	**300**	**91.5**
Floway width	**5**	**1.5**
Floway Area	**1,500**	**139**

	Operational time days	Hydraulic Load for period gallons	Hydraulic Load average per operational day gallons	Areal Hydraulic loading rate cm/day	Linear Hydraulic Loading Rate gallons/minute-lf
5/17/2004	6	986,787	164,465	447	22.8
5/24/2004	7	1,204,631	165,427	449	23.0
6/1/2004	7	1,157,989	162,731	442	22.6
6/7/2004	7	1,139,115	180,800	491	25.1
6/14/2004*	7	1,265,598	176,760	480	24.6
6/21/2004*	7	1,237,320	168,480	458	23.4
6/28/2004*	7	1,179,360	137,808	374	19.1
7/5/2004*	3	964,656	190,847	518	26.5
7/12/2004	7	572,540	131,743	358	18.3
7/19/2004	7	922,204	140,876	383	19.6
7/26/2004	7	986,135	122,129	332	17.0
8/2/2004	7	854,905	140,529	382	19.5
8/9/2004	7	983,700	102,346	278	14.2
8/16/2004	5	716,421	163,570	444	22.7
8/23/2004	7	817,852	84,798	230	11.8
8/30/2004	5	593,587	118,717	322	16.5
9/9/2004	4.5	477,922	106,205	288	14.8
9/13/2004	Hurricane Frances				
9/20/2004	5.5	676,702	123,037	334	17.1
9/26/2004	6	646,547	107,758	293	15.0
10/4/2004	Hurricane Jeanne				
10/11/2004	7	716,025	102,289	278	14.2
10/18/2004	7	1,008,234	144,033	391	20.0
10/25/2004	7	830,325	118,618	322	16.5
11/1/2004	7	905,817	129,402	351	18.0
11/8/2004	7	867,933	123,990	337	17.2
11/15/2004	7	864,060	123,437	335	17.1
11/22/2004	7	858,542	122,649	333	17.0
11/29/2004	7	873,224	124,746	339	17.3
12/5/2004	6	784,534	130,756	355	18.2
TOTAL POR	181	25,092,665	138,634	377	19.3
TOTAL Adjusted POR	151	20,580,448	136,294	370	18.9

*Totalizer not functioning, flows calculated from average instantaneous rate
Adjusted POR excludes shaded area influenced by Hurricanes

Table 2-3: Hydraulic Loading Parameters single-stage ATS™ floway North

	ft or ft^2	m or m^2
Floway length	**320**	**97.6**
Floway width	**5**	**1.5**
Floway Area	**1,600**	**149**

	Operational time days	**Hydraulic Load for period gallons**	**Hydraulic Load average per operational day gallons**	**Areal Hydraulic loading rate cm/day**	**Linear Hydraulic Loading Rate gallons/minute-lf**
5/17/2004	**6**	**454,581**	**75,764**	**193**	**10.5**
5/24/2004	**7**	**539,814**	**68,867**	**175**	**9.6**
5/31/2004*	**7**	**482,069**	**67,379**	**172**	**9.4**
6/7/2004*	**7**	**471,653**	**65,520**	**167**	**9.1**
6/14/2004	**7**	**458,640**	**67,752**	**173**	**9.4**
6/21/2004*	**7**	**474,264**	**63,216**	**161**	**8.8**
6/28/2004	**7**	**442,512**	**58,925**	**150**	**8.2**
7/5/2004	**3**	**412,474**	**78,968**	**201**	**11.0**
7/12/2004	**7**	**236,905**	**68,866**	**175**	**9.6**
7/19/2004	**7**	**482,063**	**67,688**	**172**	**9.4**
7/26/2004	**7**	**473,816**	**58,241**	**148**	**8.1**
8/2/2004	**7**	**407,688**	**58,335**	**149**	**8.1**
8/9/2004	**7**	**408,342**	**34,248**	**87**	**4.8**
8/16/2004	**5**	**239,736**	**22,450**	**57**	**3.1**
8/23/2004	**7**	**112,249**	**46,536**	**119**	**6.5**
8/30/2004	**5**	**325,755**	**65,151**	**166**	**9.0**
9/9/2004	**4.5**	**245,114**	**54,470**	**139**	**7.6**
9/13/2004	**Hurricane Frances**				
9/20/2004	**5.5**	**119,918**	**21,803**	**56**	**3.0**
9/26/2004	**6**	**356,832**	**59,472**	**151**	**8.3**
10/4/2004	**Hurricane Jeanne**				
10/11/2004	**7**	**355,392**	**50,770**	**138**	**7.1**
10/18/2004	**7**	**328,092**	**46,870**	**127**	**6.5**
10/25/2004	**7**	**402,480**	**57,497**	**156**	**8.0**
11/1/2004	**7**	**443,232**	**63,319**	**172**	**8.8**
11/8/2004	**7**	**364,124**	**52,018**	**141**	**7.2**
11/15/2004	**7**	**453,884**	**64,841**	**176**	**9.0**
11/22/2004	**7**	**459,207**	**65,601**	**178**	**9.1**
11/29/2004	**7**	**465,499**	**66,500**	**181**	**9.2**
TOTAL POR	**175**	**10,416,335**	**59,522**	**152**	**8.3**
TOTAL Adjusted POR	**139**	**8,556,406**	**61,557**	**157**	**8.5**

*Totalizer not functioning, flows calculated from average instantaneous rate
Adjusted POR excludes shaded area influenced by Hurricanes

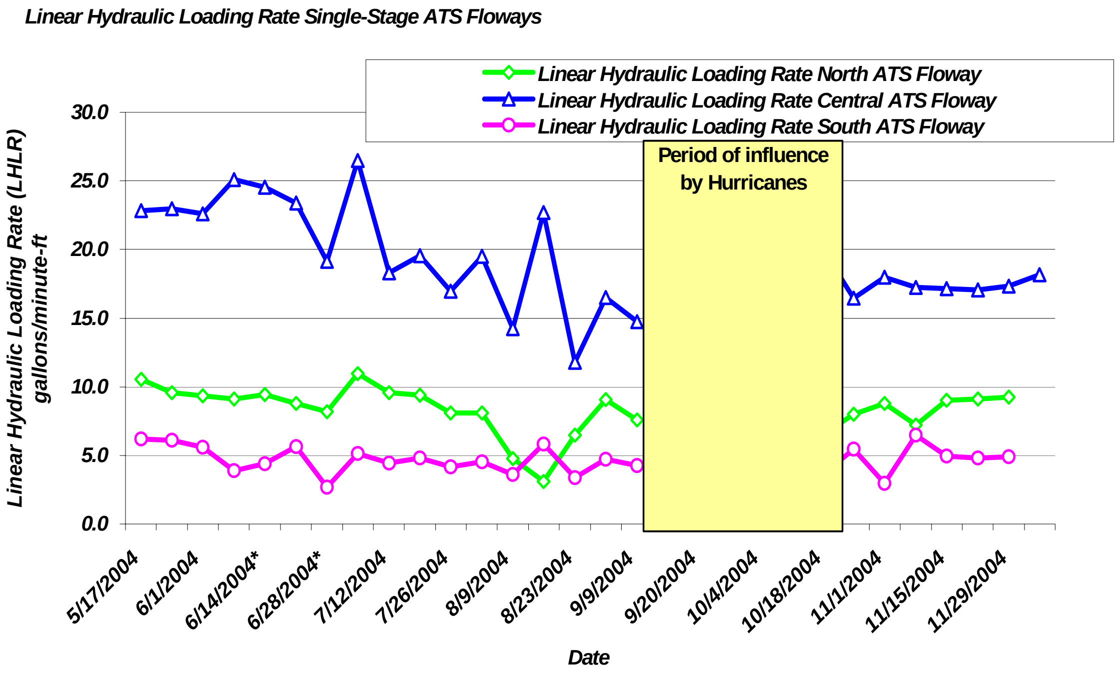


Figure 2-1: Linear Hydraulic Loading Rate (LHLR) May 11,to December 5, 2004 single-stage ATS™ floways**.**

INFLUENT AND EFFLUENT WATER QUALITY

Phosphorus and Nitrogen Concentrations

Analytical water quality results for nitrogen and phosphorus are noted within Tables 2-4 through 2-6, and are graphically illustrated in Figures 2-2 through 2-4.

The mean influent total phosphorus concentration to the South floway was 336 ppb, with the mean effluent total phosphorus concentration at 250 ppb. The mean influent total phosphorus concentration to the North floway was 336 ppb, with the mean effluent total phosphorus concentration at 249 ppb. The mean influent total phosphorus concentration to the Central floway was 333 ppb, with the mean effluent total phosphorus concentration at 258 ppb.

The mean influent total nitrogen concentrations to the South floway were 1.85 mg/l, with the mean effluent total nitrogen concentration at 1.27 ppb. The mean influent total nitrogen concentration to the North floway was 1.85 mg/l, with the mean effluent total nitrogen concentration at 1.30 ppb. The mean influent total nitrogen concentration to the Central floway was 1.85 mg/l, with the mean effluent total nitrogen concentration at 1.32 ppb.

Table 2-4: South ATS™ floway nitrogen and phosphorus analysis

	South ATS Floway Effluent											
	Total Phosphorus ppb		Ortho Phosphorus ppb		Total Nitrogen mg/l		TKN mg/l		Nitrate N mg/l		Ammonia N mg/l	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
5/17/2004	211	130	141	34	1.39	1.20	1.39	1.20	BDL	BDL	0.15	BDL
5/24/2004	240	140	91	43	1.70	1.10	1.7	1.10	BDL	BDL	0.05	BDL
6/1/2004	305	130	87	42	2.58	1.44	2.58	1.40	BDL	0.04	0.25	0.04
6/7/2004	235	120	122	32	2.59	1.20	2.59	1.20	0.03	BDL	0.27	BDL
6/14/2004	164	67	61	18	2.24	1.15	2.21	1.10	0.03	BDL	0.32	0.019
6/21/2004	148	64	62	19	1.96	1.00	1.94	1.00	0.02	BDL	0.27	BDL
6/28/2004	110	39	46	7	1.87	1.10	1.86	1.10	0.01	BDL	0.17	BDL
7/5/2004	85	28	39	No Data	1.70	BDL	1.69	BDL	0.01	BDL	0.11	BDL
7/12/2004	99	44	39	7	1.39	1.20	1.39	1.20	BDL	BDL	0.15	BDL
7/19/2004	49	46	1	0	1.41	0.96	1.21	0.96	0.2	BDL	0.02	BDL
7/26/2004	82	40	No Data	4	1.10	1.00	1.10	1.00	BDL	BDL	0.07	0.02
8/2/2004	79	31	8	5	1.47	0.94	1.47	0.94	BDL	BDL	0.13	BDL
8/9/2004	70	43	8	7	1.14	0.78	1.14	0.78	BDL	BDL	0.07	0.01
8/16/2004	90	36	22	11	1.30	1.10	1.30	1.10	BDL	BDL	0.35	BDL
8/23/2004	422	250	300	211	2.60	1.80	2.60	1.80	BDL	BDL	0.28	BDL
8/30/2004	843	500	629	431	2.67	1.62	2.67	1.60	BDL	0.02	0.58	BDL
9/9/2004	640	700	No Data	No Data	2.00	1.60	2.00	1.60	BDL	BDL	0.84	0.29
9/13/2004			Power Outage Hurricane Frances- No Data									
9/21/2004	993	860	798	710	2.89	1.55	2.89	1.50	BDL	0.05	0.45	0.01
9/27/2004	720	660	No Data	No Data	2.40	1.50	2.40	1.50	BDL	BDL	0.48	BDL
10/3/2004			Power Outage Hurricane Jeanne- No Data									
10/11/2004	943	1,000	855	1,000	2.83	1.13	2.58	1.10	0.27	0.03	BDL	0.02
10/18/2004	961	1,000	849	948	1.98	1.80	1.93	1.80	0.05	BDL	0.01	BDL
10/25/2004	920	850	920	850	1.43	1.13	1.40	1.10	0.03	0.03	0.14	BDL
11/1/2004	860	800	736	696	2.44	1.78	2.40	1.70	0.04	0.08	0.12	BDL
11/8/2004	730	700	590	603	2.37	2.89	2.30	2.80	0.07	0.09	0.1	BDL
11/15/2004	650	600	527	556	1.71	1.43	1.60	1.30	0.11	0.13	0.16	BDL
11/22/2004	510	490	374	512	2.04	1.97	1.90	1.80	0.14	0.17	0.057	BDL
11/29/2004	360	240	186	171	1.15	1.07	1.00	0.98	0.15	0.085	0.05	BDL

Note: Shaded Area represents data influenced by Hurricanes, including start-up period after prolonged power outage.

Table 2-5: North ATS™ floway nitrogen and phosphorus analysis.

	North ATS Floway Effluent											
	Total Phosphorus ppb		Ortho Phosphorus ppb		Total Nitrogen mg/l		TKN mg/l		Nitrate N mg/l		Ammonia N mg/l	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
5/17/2004	211	130	141	31	1.39	1.10	1.39	1.10	BDL	BDL	0.15	BDL
5/24/2004	240	180	91	33	1.70	1.50	1.7	1.50	BDL	0.02	0.05	BDL
6/1/2004	305	140	87	36	2.58	1.80	2.58	1.80	BDL	BDL	0.25	BDL
6/7/2004	235	150	122	45	2.59	1.41	2.59	1.41	0.03	0.11	0.27	0.05
6/14/2004	164	74	61	18	2.24	1.00	2.21	1.00	0.03	BDL	0.32	0.02
6/21/2004	148	72	62	15	1.96	1.20	1.94	1.20	0.02	BDL	0.27	0.01
6/28/2004	110	55	46	11	1.87	1.20	1.86	1.20	0.01	BDL	0.17	BDL
7/5/2004	85	30	39	No Data	1.70	0.74	1.69	0.74	0.01	BDL	0.11	BDL
7/12/2004	99	36	39	6	1.39	1.10	1.39	1.10	BDL	BDL	0.15	BDL
7/19/2004	49	33	1	No Data	1.41	0.80	1.21	0.80	0.2	BDL	0.02	BDL
7/26/2004	82	36	No Data	3	1.10	1.00	1.10	1.00	BDL	BDL	0.07	BDL
8/2/2004	79	31	8	5	1.47	0.84	1.47	0.84	BDL	BDL	0.13	0.01
8/9/2004	70	35	8	6	1.14	0.77	1.14	0.77	BDL	0.02	0.07	0.01
8/16/2004	90	71	22	23	1.30	1.10	1.30	1.10	BDL	BDL	0.35	BDL
8/23/2004	422	230	300	188	2.60	1.60	2.60	1.60	BDL	BDL	0.28	0.01
8/30/2004	843	520	629	438	2.67	1.90	2.67	1.90	BDL	BDL	0.58	BDL
9/9/2004	640	760			2.00	2.30	2.00	2.30	BDL	BDL	0.84	0.47
9/13/2004				Power Outage Hurricane Frances- No Data								
9/21/2004	993	670	798	439	2.89	1.47	2.89	1.47	BDL	0.07	0.45	BDL
9/27/2004	720	650			2.40	1.50	2.40	1.50	BDL	BDL	0.48	BDL
10/3/2004				Power Outage Hurricane Jeanne- No Data								
10/11/2004	943	1,100	855	1,100	2.83	2.14	2.58	2.10	0.27	0.04	BDL	0.18
10/18/2004	961	1,000	849	948	1.98	1.80	1.93	1.80	0.05	BDL	0.01	BDL
10/25/2004	920	820	920	No Data	1.43	1.12	1.40	1.10	0.03	0.02	0.14	BDL
11/1/2004	860	770	736	686	2.44	2.02	2.40	2.00	0.04	0.02	0.12	BDL
11/8/2004	730	650	590	No Data	2.37	2.14	2.30	2.10	0.07	0.04	0.1	BDL
11/15/2004	650	570	527	499	1.71	1.44	1.60	1.40	0.11	0.04	0.16	BDL
11/22/2004	510	430	374	360	2.04	1.65	1.90	1.60	0.14	0.053	0.057	BDL
11/29/2004	360	290	186	200	1.15	1.00	1.00	1.00	0.15	BDL	0.05	BDL

Note: Shaded Area represents data influenced by Hurricanes, including start-up period after prolonged power outage.

Table 2-6: Central ATS™ floway nitrogen and phosphorus analysis

	Central ATS Floway Effluent											
	Total Phosphorus ppb		Ortho Phosphorus ppb		Total Nitrogen mg/l		TKN mg/l		Nitrate N mg/l		Ammonia N mg/l	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
5/17/2004	211	160	141	34	1.39	1.10	1.39	1.10	BDL	BDL	0.15	0.01
5/24/2004	240	140	91	27	1.70	1.30	1.7	1.30	BDL	BDL	0.05	BDL
6/1/2004	305	140	87	26	2.58	1.90	2.58	1.90	BDL	BDL	0.25	BDL
6/7/2004	235	120	122	20	2.59	1.20	2.59	1.20	0.03	BDL	0.27	0.03
6/14/2004	164	94	61	21	2.24	1.34	2.21	1.27	0.03	0.07	0.32	0.02
6/21/2004	148	90	62	19	1.96	1.10	1.94	1.10	0.02	BDL	0.27	0.01
6/28/2004	110	66	46	12	1.87	1.20	1.86	1.20	0.01	BDL	0.17	0.01
7/5/2004	85	44	39	No Data	1.70	0.81	1.69	0.81	0.01	BDL	0.11	BDL
7/12/2004	99	55	39	6	1.39	1.20	1.39	1.20	BDL	BDL	0.15	BDL
7/19/2004	49	46	1	No Data	1.41	0.89	1.21	0.89	0.2	BDL	0.02	BDL
7/26/2004	82	51	No Data	5	1.10	1.10	1.10	1.10	BDL	BDL	0.07	BDL
8/2/2004	79	52	8	8	1.47	0.90	1.47	0.90	BDL	BDL	0.13	BDL
8/9/2004	70	46	8	6	1.14	0.78	1.14	0.78	BDL	0.02	0.07	0.02
8/16/2004	90	49	22	17	1.30	0.93	1.30	0.93	BDL	BDL	0.35	BDL
8/23/2004	422	270	300	228	2.60	1.82	2.60	1.80	BDL	0.02	0.28	BDL
8/30/2004	843	520	629	448	2.67	1.80	2.67	1.80	BDL	BDL	0.58	0.039
9/9/2004	640	1,200	No Data	No Data	2.00	2.66	2.00	2.60	BDL	0.06	0.84	0.51
9/13/2004			Power Outage Hurricane Frances- No Data									
9/21/2004	993	880	798	723	2.89	2.00	2.89	2.00	BDL	BDL	0.45	0.01
9/27/2004	720	670	No Data	No Data	2.40	1.40	2.40	1.40	BDL	BDL	0.48	BDL
10/3/2004			Power Outage Hurricane Jeanne- No Data									
10/11/2004	943	1,100	855	1,089	2.83	1.38	2.58	1.30	0.27	0.05	BDL	BDL
10/18/2004	961	1,000	849	948	1.98	1.70	1.93	1.70	0.05	BDL	0.01	BDL
10/25/2004	920	840	920	830	1.43	1.12	1.40	1.10	0.03	0.02	0.14	BDL
11/1/2004	860	770	736	676	2.44	1.65	2.40	1.60	0.04	0.05	0.12	BDL
11/8/2004	730	690	590		2.37	1.97	2.30	1.90	0.07	0.07	0.1	BDL
11/15/2004	650	610	527	556	1.71	1.90	1.60	1.80	0.11	0.1	0.16	BDL
11/22/2004	510	470	374	378	2.04	1.83	1.90	1.70	0.14	0.13	0.057	BDL
11/29/2004	360	310	186	195	1.15	1.03	1.00	0.96	0.15	0.07	0.05	BDL
12/6/2004	270	210	106	35	1.74	1.29	1.60	1.20	0.14	0.09	0.028	BDL

Note: Shaded Area represents data influenced by Hurricanes, including start-up period after prolonged power outage.

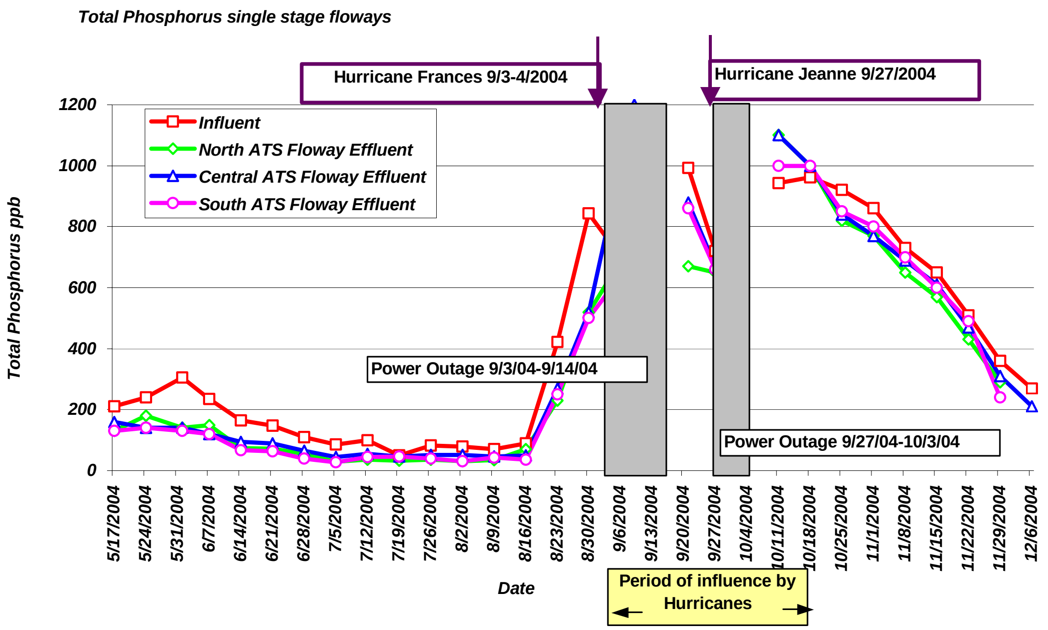


Figure 2-2: Total phosphorus concentration profiles May 11 to December 5, 2004 single-stage ATS™ floways

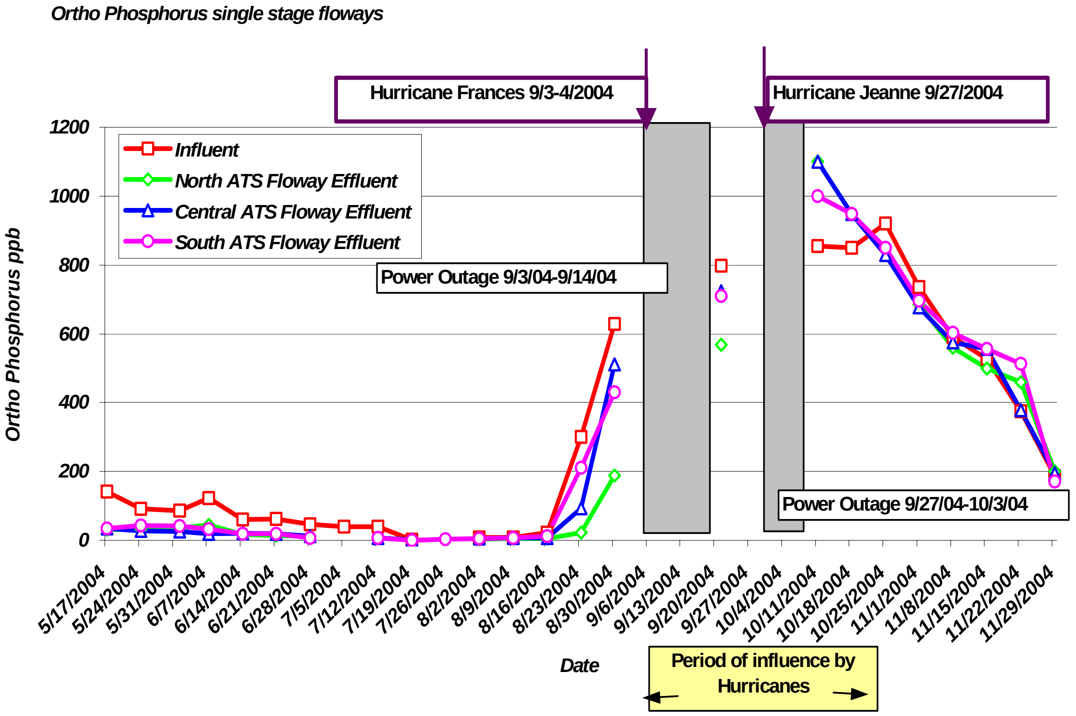


Figure 2-3: Ortho phosphorus concentration profiles May 11 to December 5, 2004 single-stage ATS™ floways

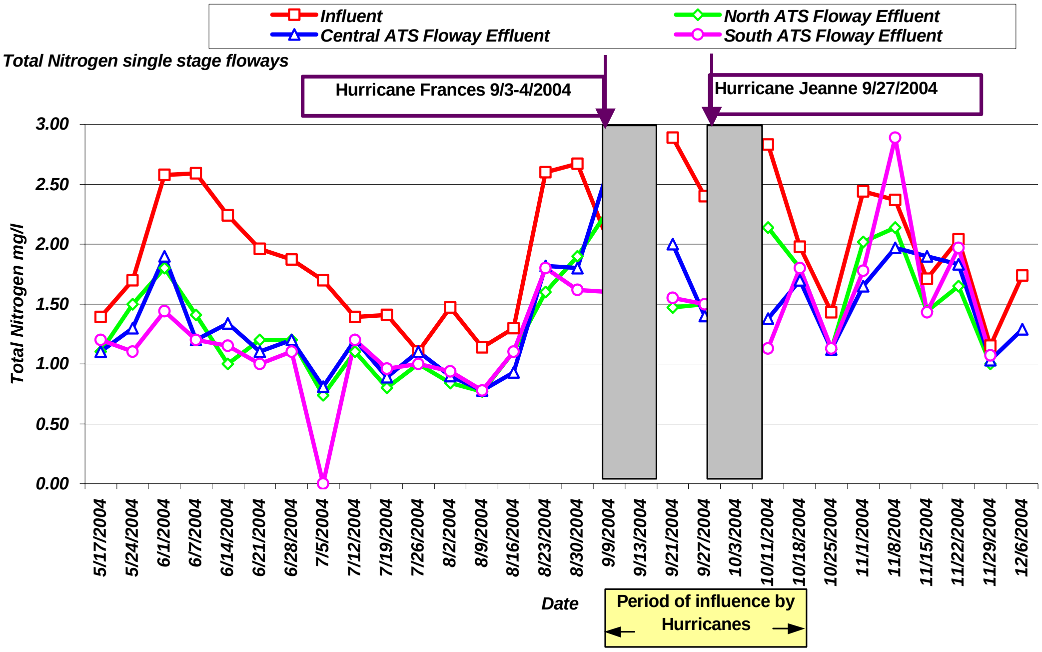


Figure 2-4: Total Nitrogen concentration profiles May 11 to December 5, 2004 single-stage ATS™ floways

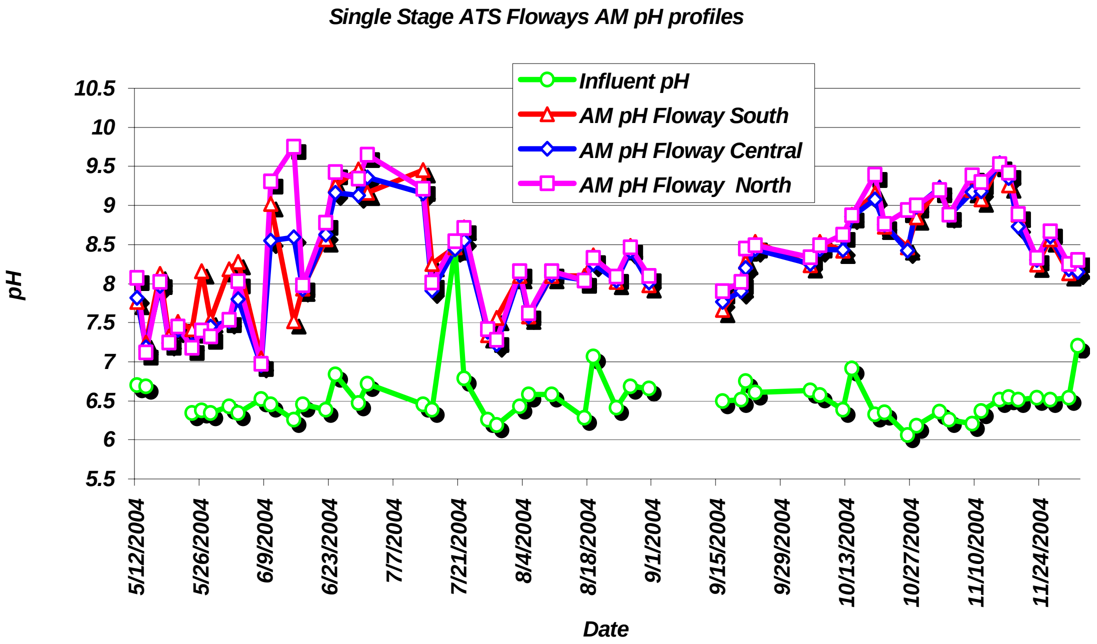
Water Temperature, pH and Dissolved Oxygen

Results of AM and PM field monitoring of pH, dissolved oxygen and water temperature extended through November 29, 2004, are presented within Table 2-7 and Figures 2-5 through 2-7. Morning (AM) samplings were typically done between 8:00 AM and 11:00 PM. The afternoon (PM) samplings were typically done between 1:00 PM and 5:00 PM.

Water passing through the ATS™ treatment units experienced increases in pH, dissolved oxygen and temperature. For the South, North and Central floways the mean pH increased from 6.51 to 8.49, 8.51 and 8.36, respectively. This increase is due to consumption of carbon dioxide by the algal turf through photosynthesis. Dissolved oxygen increased from 4.47 to 9.81, 9.96 and 9.27 mg/l for the South, North and Central floways, respectively. Temperature increased slightly from a mean influent temperature of 27.89 to 29.69, 29.45 and 29.12 for the South, North and Central floways, respectively.

Table 2-7: pH, dissolved oxygen and water temperature statistical summary single-stage ATS™ floways

	Morning (AM)				Afternoon (AM)				Combined			
	Influent	South Floway	Central Floway	North Floway	Influent	South Floway	Central Floway	North Floway	Influent	South Floway	Central Floway	North Floway
pH mean	6.57	8.34	8.27	8.40	6.45	8.62	8.43	8.60	6.51	8.49	8.36	8.51
pH max	8.45	9.54	9.54	9.75	6.95	9.45	9.34	9.81	8.45	9.54	9.54	9.81
pH min	6.19	7.04	6.96	6.97	6.05	7.39	7.12	7.10	6.02	7.04	6.96	6.97
pH standard deviation	0.39	0.63	0.65	0.73	0.22	0.48	0.47	0.54	0.30	0.57	0.56	0.64
DO mean mg/l	3.14	10.15	9.56	10.17	3.49	9.52	9.02	9.78	4.47	9.81	9.27	9.96
DO max mg/l	6.07	19.28	15.16	19.03	7.76	15.58	13.36	14.54	7.76	19.28	15.16	19.03
DO min mg/l	0.08	5.11	4.84	5.18	0.10	4.70	4.65	4.83	0.08	4.70	4.65	4.83
DO standard deviation mg/l	1.87	2.94	2.37	3.08	2.15	2.19	1.84	2.10	2.03	2.57	2.10	2.58
Water T mean C	27.44	29.04	28.35	28.74	28.24	31.29	30.75	31.07	27.89	29.69	29.12	29.45
Water T max C	30.00	39.60	37.00	39.00	31.50	39.60	37.00	39.00	31.50	39.60	37.00	39.00
Water T min C	24.20	21.20	21.20	21.10	23.30	26.00	25.80	25.90	23.30	21.20	21.20	21.10
Water T standard deviation C	1.55	3.61	3.11	3.47	1.48	3.07	2.63	3.00	1.56	3.81	3.39	3.68



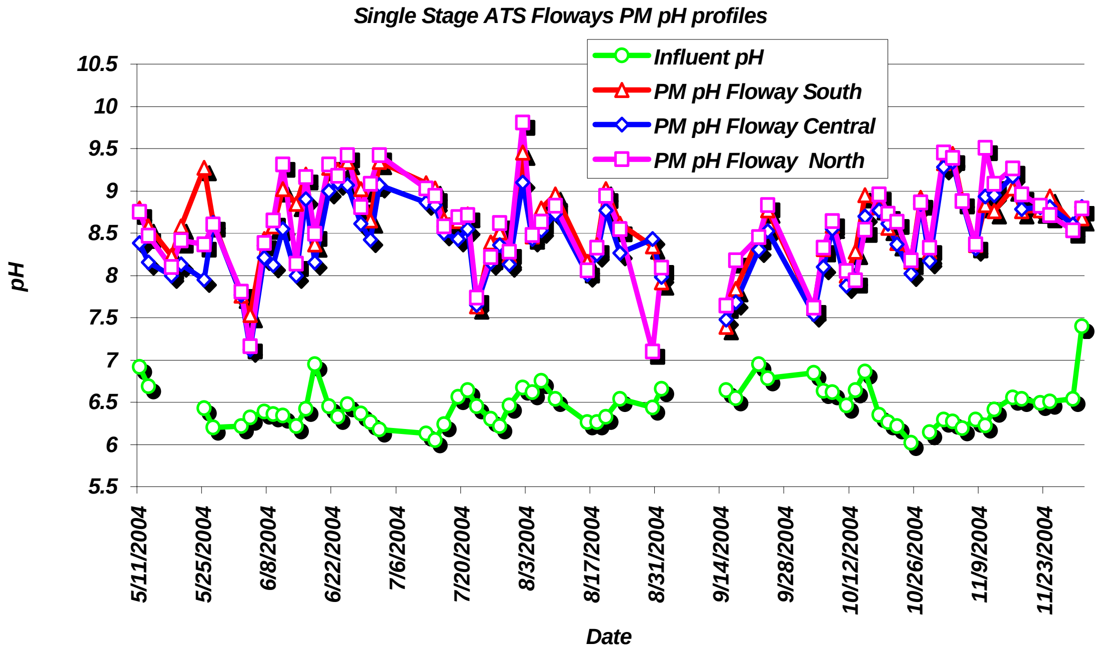
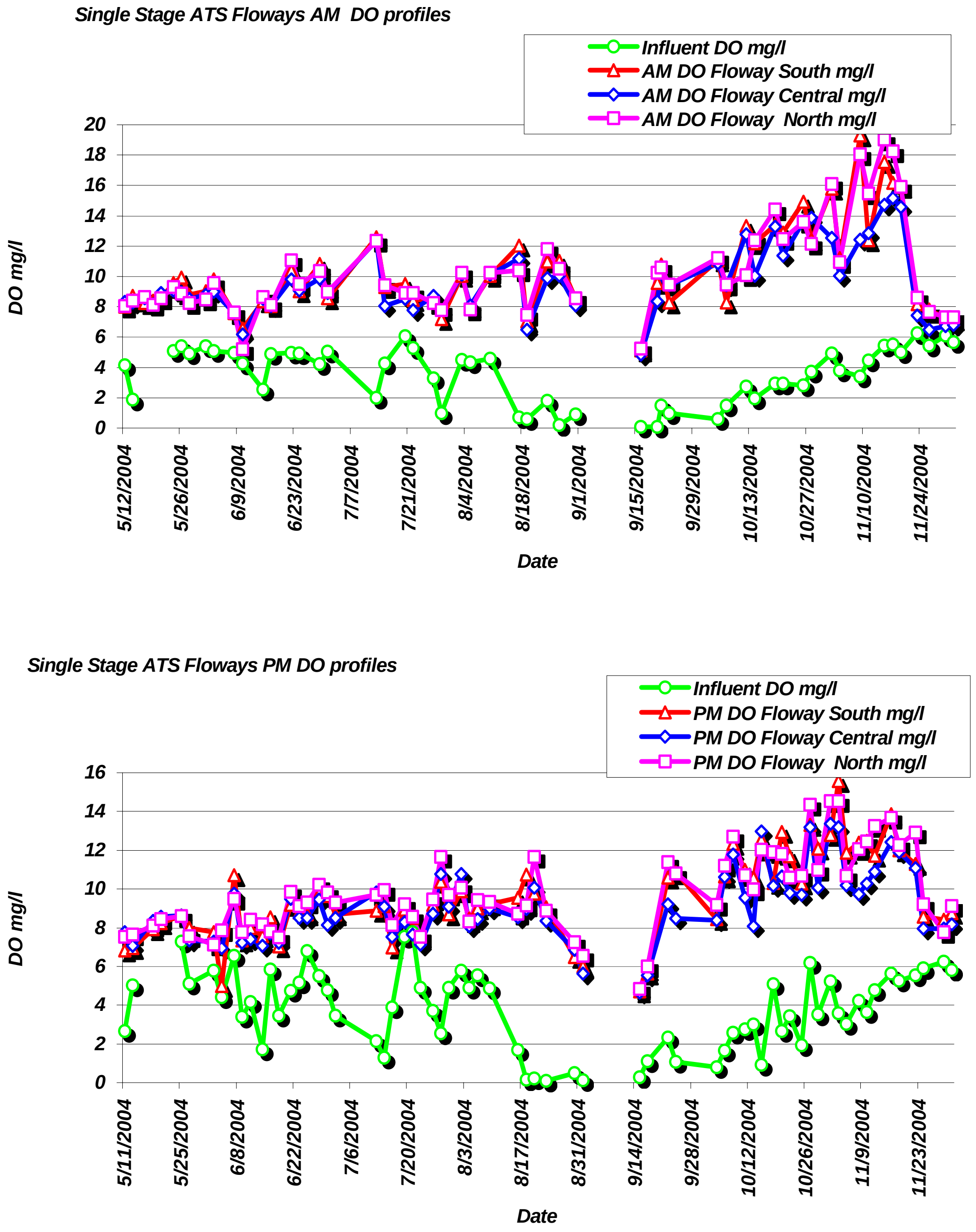
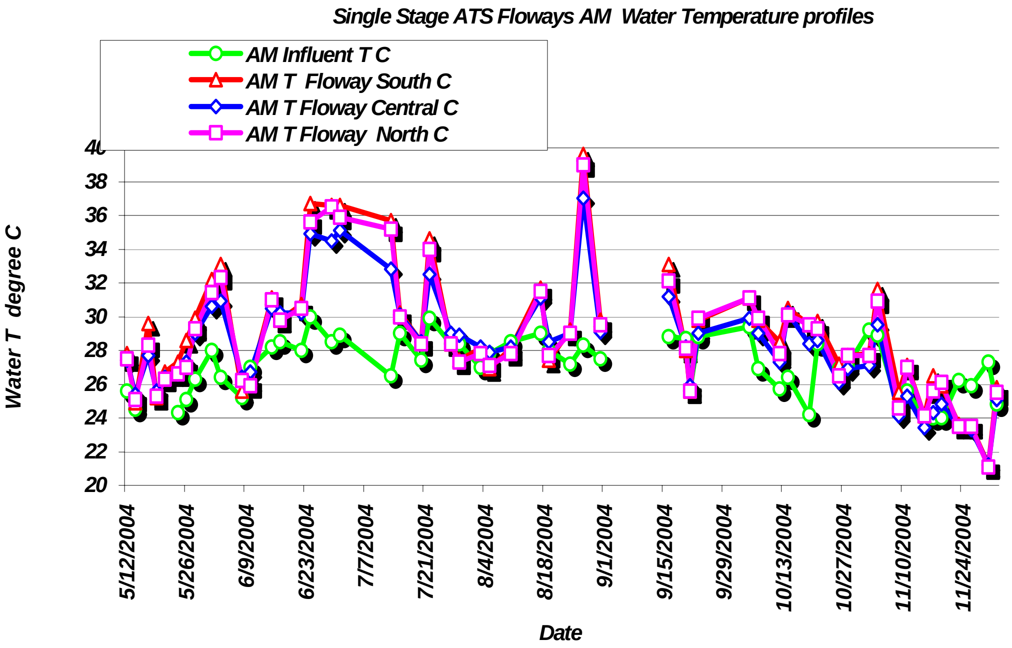


Figure 2-5: pH profiles for single-stage ATS™


Single Stage ATS Floways AM DO profiles

Single Stage ATS Floways PM DO profiles

Figure 2-6: Dissolved oxygen profiles for single-stage ATS™



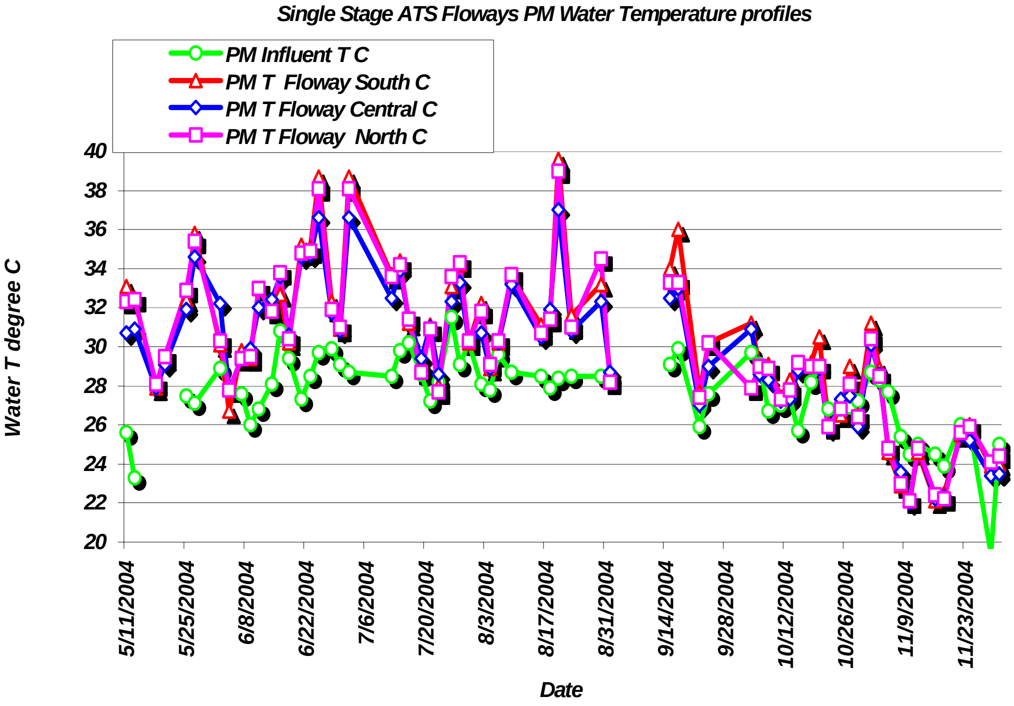


Figure 2-7: Water temperature profiles for single-stage ATS™

ANALYSIS OF PHOSPHORUS REDUCTION

Provided in Table 2-8 is a summary of phosphorus, nitrogen and hydraulic loads and removal rates for the three independent single Stage ATS™ floways for the POR.

Calculated weekly phosphorus loads and load removal rates are presented in Tables 2-9 through 2-11. Noted in Figure 2-8 are the loading and removal graphs for phosphorus.

The South floway during the POR received total phosphorus at a mean loading rate of 109 g/m^2-yr. The South system removed total phosphorus at the mean rate 25 g/m^2-yr (24.08% removal). The mean influent total phosphorus concentration to the South floway was 336 ppb, with the mean effluent total phosphorus concentration at 250 ppb.

The North floway received total phosphorus at a mean loading rate of 157 g/m^2-yr. The North system removed total phosphorus at the mean rate 47 g/m^2-yr (24.85% removal). The mean influent total phosphorus concentration to the North floway was 336 ppb, with the mean effluent total phosphorus concentration at 249 ppb.

The Central floway received total phosphorus at a mean loading rate of 397 g/m^2-yr. The Central system removed total phosphorus at the mean rate 92 g/m^2-yr (23.08% removal). The mean influent total phosphorus concentration to the Central floway was 333 ppb, with the mean effluent total phosphorus concentration at 258 ppb.

Table 2-8: Mean Performance Summary three single-stage ATS™ Floways for May11 to December 5, 2004 for Adjusted POR.

Floway	Area m^2	Width ft	Adjusted POR Mean HLR cm/day	Adjusted POR Mean LHLR gpm/ft	Adjusted POR Mean Influent		Adjusted POR Mean Effluent		Adjusted POR Mean Influent Loading		Adjusted POR Mean Effluent Removal	
					TP ppb	TN mg/l	TP ppb	TN mg/l	TP g/m^2-yr	TN g/m^2-yr	TP g/m^2-yr	TN g/m^2-yr
South	**139**	**5**	**92**	**4.7**	**336**	**1.85**	**250**	**1.27**	**109**	**624**	**25**	**181**
Central	**139**	**5**	**368**	**18.8**	**333**	**1.85**	**258**	**1.32**	**397**	**2,428**	**92**	**722**
North	**149**	**5**	**157**	**8.5**	**336**	**1.85**	**249**	**1.30**	**189**	**1,120**	**47**	**332**

Table 2-9: South ATS™ Floway Total Phosphorus Loading and Removal Parameters. Totals represent mean value for concentration (ppb), rate (g/m^2/yr) and percent (%) parameters; and summed value for load (lbs).

	South ATS Floway						
	Total Phosphorus ppb						
	Influent	Effluent	Influent load lbs	Effluent load lbs	Influent areal loading rate gm/m^2-yr	Effluent areal removal rate gm/m^2-yr	Percent Removal
5/17/2004	211	130	0.47	0.29	93	36	38.39%
5/24/2004	240	140	0.61	0.36	104	43	41.67%
5/31/2004	305	130	0.72	0.31	122	70	57.38%
6/7/2004*	235	120	0.39	0.20	65	32	48.94%
6/14/2004	164	67	0.32	0.13	54	32	59.15%
6/21/2004	148	64	0.27	0.12	47	26	56.76%
6/28/2004	110	39	0.26	0.09	44	28	64.55%
7/5/2004	85	28	0.10	0.03	38	26	67.06%
7/12/2004	99	44	0.09	0.04	16	9	55.56%
7/19/2004	49	46	0.09	0.09	16	1	6.12%
7/26/2004	82	40	0.17	0.08	28	14	51.22%
8/2/2004	79	31	0.14	0.05	23	14	60.76%
8/9/2004	70	43	0.13	0.08	23	9	38.57%
8/16/2004	90	36	0.14	0.05	32	19	60.00%
8/23/2004	422	250	0.74	0.44	125	51	40.76%
8/30/2004	843	500	1.19	0.71	284	115	40.69%
9/9/2004	640	700	0.73	0.80	181	-17	-9.37%
9/13/2004	Hurricane Frances						
9/20/2004	993	860	1.26	1.09	255	34	13.39%
9/26/2004	720	660	0.98	0.90	182	15	8.33%
10/4/2004	Hurricane Jeanne						
10/11/2004	943	1,000	1.58	1.68	252	-15	-6.04%
10/18/2004	961	1,000	1.45	1.51	231	-9	-4.06%
10/25/2004	920	850	2.12	1.95	337	26	7.61%
11/1/2004	860	800	1.07	0.99	170	12	6.98%
11/8/2004	730	700	1.99	1.91	316	13	4.11%
11/15/2004	650	600	1.35	1.24	214	16	7.69%
11/22/2004	510	490	1.03	0.99	164	6	3.92%
11/29/2004	360	240	0.74	0.49	118	39	33.33%
TOTAL POR	427	356	20.12	16.63	128	22	17.37%
TOTAL Adjusted POR	336	250	13.65	10.36	109	26	24.08%

*Totalizer not functioning, flows calculated from average instantaneous rate

Adjusted POR excludes shaded area influenced by Hurricanes

Table 2-10: North ATS™ Floway Total Phosphorus Loading and Removal Parameters. Totals represent mean value for concentration (ppb), rate (g/m^2/yr) and percent (%) parameters; and summed value for load (lbs).

	North ATS Floway Effluent						
	Total Phosphorus ppb						
	Influent	Effluent	Influent load lbs	Effluent load lbs	Influent areal loading rate gm/m^2-yr	Effluent areal removal rate gm/m^2-yr	Percent Removal
5/17/2004	211	130	0.80	0.49	149	57	38.39%
5/24/2004	240	180	1.08	0.81	172	43	25.00%
5/31/2004*	305	140	1.23	0.56	195	106	54.10%
6/7/2004*	235	150	0.92	0.59	147	53	36.17%
6/14/2004	164	74	0.63	0.28	100	55	54.88%
6/21/2004*	148	72	0.59	0.28	93	48	51.35%
6/28/2004	110	55	0.41	0.20	65	32	50.00%
7/5/2004	85	30	0.29	0.10	109	70	64.71%
7/12/2004	99	36	0.20	0.07	31	20	63.64%
7/19/2004	49	33	0.20	0.13	31	10	32.65%
7/26/2004	82	36	0.32	0.14	52	29	56.10%
8/2/2004	79	31	0.27	0.11	43	26	60.76%
8/9/2004	70	35	0.24	0.12	38	19	50.00%
8/16/2004	90	71	0.18	0.14	40	8	21.11%
8/23/2004	422	230	0.40	0.22	63	29	45.50%
8/30/2004	843	520	2.29	1.41	510	196	38.32%
9/9/2004	640	760	1.31	1.55	324	-61	-18.75%
9/13/2004	Hurricane Frances						
9/20/2004	993	670	0.99	0.67	201	65	32.53%
9/26/2004	720	650	2.14	1.93	398	39	9.72%
10/4/2004	Hurricane Jeanne						
10/11/2004	943	1,100	2.80	3.26	445	-74	-16.65%
10/18/2004	961	1,000	2.63	2.74	419	-17	-4.06%
10/25/2004	920	820	3.09	2.75	492	53	10.87%
11/1/2004	860	770	3.18	2.85	506	53	10.47%
11/8/2004	730	650	2.22	1.97	353	39	10.96%
11/15/2004	650	570	2.46	2.16	392	48	12.31%
11/22/2004	510	430	1.95	1.65	311	49	15.69%
11/29/2004	360	290	1.40	1.13	222	43	19.44%
TOTAL POR	427	353	34.20	28.33	218	37	17.16%
TOTAL Adjusted POR	336	249	23.53	17.68	189	47	24.85%

*Totalizer not functioning, flows calculated from average instantaneous rate
Adjusted POR excludes shaded area influenced by Hurricanes

Table 2-11: Central ATS™ Floway Total Phosphorus Loading and Removal Parameters. Totals represent mean value for concentration (ppb), rate (g/m^2/yr) and percent (%) parameters; and summed value for load (lbs).

	Central ATS Floway Effluent						
	Total Phosphorus ppb						
	Influent	Effluent	Influent load lbs	Effluent load lbs	Influent areal loading rate gm/m^2-yr	Effluent areal removal rate gm/m^2-yr	Percent Removal
5/17/2004	211	160	1.74	1.32	344	83	24.17%
5/24/2004	240	140	2.41	1.41	384	160	41.67%
6/1/2004	305	140	2.95	1.35	469	254	54.10%
6/7/2004	235	120	2.23	1.14	355	174	48.94%
6/14/2004*	164	94	1.73	0.99	276	118	42.68%
6/21/2004*	148	90	1.53	0.93	243	95	39.19%
6/28/2004*	110	66	1.08	0.65	172	69	40.00%
7/5/2004*	85	44	0.68	0.35	254	123	48.24%
7/12/2004	99	55	0.47	0.26	75	33	44.44%
7/19/2004	49	46	0.38	0.35	60	4	6.12%
7/26/2004	82	51	0.67	0.42	107	41	37.80%
8/2/2004	79	52	0.56	0.37	90	31	34.18%
8/9/2004	70	46	0.57	0.38	91	31	34.29%
8/16/2004	90	49	0.54	0.29	120	55	45.56%
8/23/2004	422	270	2.88	1.84	458	165	36.02%
8/30/2004	843	520	4.17	2.57	930	356	38.32%
9/9/2004	640	1,200	2.55	4.78	632	-553	-87.50%
9/13/2004	Hurricane Frances						
9/20/2004	993	880	5.60	4.97	1,135	129	11.38%
9/26/2004	720	670	3.88	3.61	721	50	6.94%
10/4/2004	Hurricane Jeanne						
10/11/2004	943	1,100	5.63	6.57	896	-149	-16.65%
10/18/2004	961	1,000	8.08	8.41	1286	-52	-4.06%
10/25/2004	920	840	6.37	5.82	1014	88	8.70%
11/1/2004	860	770	6.50	5.82	1034	108	10.47%
11/8/2004	730	690	5.28	4.99	841	46	5.48%
11/15/2004	650	610	4.68	4.40	746	46	6.15%
11/22/2004	510	470	3.65	3.37	581	46	7.84%
11/29/2004	360	310	2.62	2.26	417	58	13.89%
12/5/2004	270	210	1.77	1.37	328	73	22.22%
TOTAL POR	421	382	81.23	70.99	500	63	12.60%
TOTAL Adjusted POR	333	258	53.74	41.34	397	92	23.08%

*Totalizer not functioning, flows calculated from average instantaneous rate
Adjusted POR excludes shaded area influenced by Hurricanes

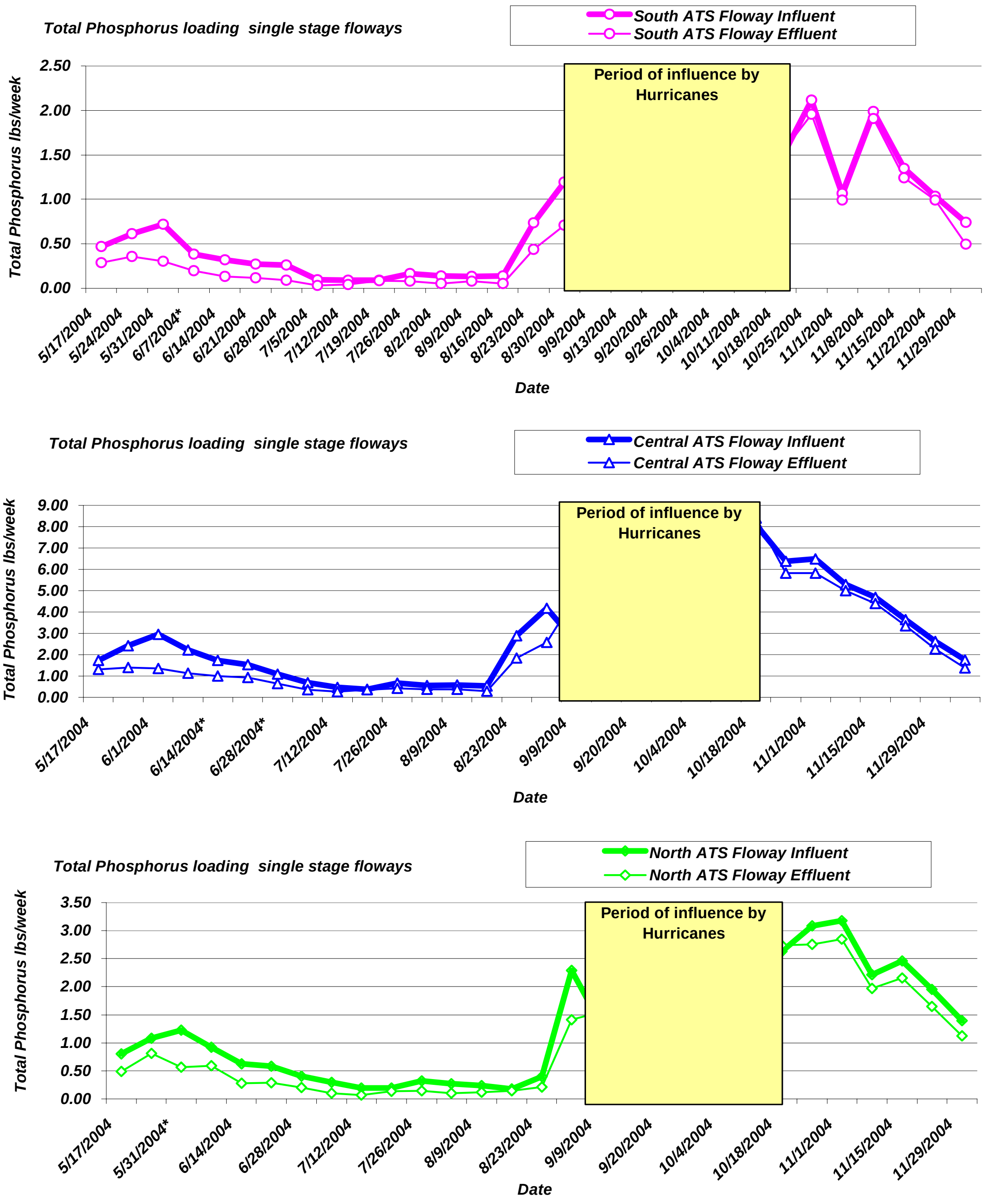


Figure 2-8: Total Phosphorus Loading and Removal May 11 to December 5, 2004 single-stage ATS™ floways

ANALYSIS OF NITROGEN REDUCTION

Calculated weekly nitrogen loads and load removal rates are presented in Tables 2-12 through 2-14. Noted in Figure 2-9 are the loading and removal graphs for nitrogen.

The South floway during the POR received total nitrogen loading rate at 624 g/m^2-yr. The South system removed total nitrogen at the mean rate of 181 g/m^2-yr (28.96 % removal). The mean influent total nitrogen concentrations to the South floway were 1.85 mg/l, with the mean effluent total nitrogen concentration at 1.27 ppb.

The North floway received total nitrogen at a mean loading rate of 1,120 g/m^2-yr. The North system removed total nitrogen at the mean rate of 332 g/m^2-yr (29.66% removal). The mean influent total nitrogen concentration to the North floway was 1.85 mg/l, with the mean effluent total nitrogen concentration at 1.30 ppb.

The Central floway received total nitrogen at a mean loading rate of 2,428 g/m^2-yr. The Central system removed total nitrogen at the mean rate of 722 g/m^2-yr (29.73% removal). The mean influent total nitrogen concentration to the Central floway was 1.85 mg/l, with the mean effluent total nitrogen concentration at 1.32 ppb.

Table 2-12: South ATS™ Floway Total Nitrogen Loading and Removal Parameters

	South ATS Floway						
	Total Nitrogen mg/l						
	Influent	**Effluent**	**Influent load lbs**	**Effluent load lbs**	**Influent areal loading rate gm/m^2-yr**	**Effluent areal removal rate gm/m^2-yr**	**Percent Removal**
5/17/2004	**1.39**	**1.20**	**3.10**	**2.68**	**615**	**84**	**13.67%**
5/24/2004	**1.70**	**1.10**	**4.36**	**2.82**	**739**	**261**	**35.29%**
5/31/2004	**2.58**	**1.44**	**6.07**	**3.39**	**1,031**	**455**	**44.19%**
6/7/2004*	**2.59**	**1.20**	**4.25**	**1.97**	**722**	**387**	**53.67%**
6/14/2004	**2.24**	**1.15**	**4.38**	**2.25**	**744**	**362**	**48.66%**
6/21/2004	**1.96**	**1.00**	**3.63**	**1.85**	**616**	**302**	**48.98%**
6/28/2004	**1.87**	**1.10**	**4.42**	**2.60**	**750**	**309**	**41.18%**
7/5/2004	**1.70**	**0.00**	**1.92**	**0.00**	**761**	**761**	**100.00%**
7/12/2004	**1.39**	**1.20**	**1.28**	**1.11**	**218**	**30**	**13.67%**
7/19/2004	**1.41**	**0.96**	**2.63**	**1.79**	**446**	**142**	**31.91%**
7/26/2004	**1.10**	**1.00**	**2.23**	**2.03**	**379**	**34**	**9.09%**
8/2/2004	**1.47**	**0.94**	**2.56**	**1.64**	**435**	**157**	**36.05%**
8/9/2004	**1.14**	**0.78**	**2.17**	**1.48**	**368**	**116**	**31.58%**
8/16/2004	**1.30**	**1.10**	**1.97**	**1.67**	**469**	**72**	**15.38%**
8/23/2004	**2.60**	**1.80**	**4.54**	**3.14**	**771**	**237**	**30.77%**
8/30/2004	**2.67**	**1.62**	**3.78**	**2.29**	**899**	**354**	**39.33%**
9/9/2004	**2.00**	**1.60**	**2.29**	**1.83**	**604**	**121**	**20.00%**
9/13/2004	**Hurricane Frances**						
9/20/2004	**2.89**	**1.55**	**3.66**	**1.96**	**791**	**367**	**46.37%**
9/26/2004	**2.40**	**1.50**	**3.26**	**2.04**	**646**	**242**	**37.50%**
10/4/2004	**Hurricane Jeanne**						
10/11/2004	**2.83**	**1.13**	**4.76**	**1.90**	**808**	**485**	**60.07%**
10/18/2004	**1.98**	**1.80**	**2.99**	**2.72**	**507**	**46**	**9.09%**
10/25/2004	**1.43**	**1.13**	**3.29**	**2.60**	**558**	**117**	**20.98%**
11/1/2004	**2.44**	**1.78**	**3.03**	**2.21**	**514**	**139**	**27.05%**
11/8/2004	**2.37**	**2.89**	**6.45**	**7.87**	**1,096**	**-240**	**-21.94%**
11/15/2004	**1.71**	**1.43**	**3.54**	**2.96**	**602**	**99**	**16.37%**
11/22/2004	**2.04**	**1.97**	**4.13**	**3.99**	**702**	**24**	**3.43%**
11/29/2004	**1.15**	**1.07**	**2.37**	**2.20**	**402**	**28**	**6.96%**
TOTAL POR	**1.94**	**1.31**	**93.07**	**64.99**	**632**	**191**	**30.17%**
TOTAL Adjusted POR	**1.85**	**1.27**	**73.01**	**51.87**	**624**	**181**	**28.96%**

*Totalizer not functioning, flows calculated from average instantaneous rate
Adjusted POR excludes shaded area influenced by Hurricanes

Table 2-13: North ATS™ Floway Total Nitrogen Loading and Removal Parameters

	North ATS Floway Effluent						
	Total Nitrogen mg/l						
	Influent	Effluent	Influent load lbs	Effluent load lbs	Influent areal loading rate gm/m^2-yr	Effluent areal removal rate gm/m^2-yr	Percent Removal
5/17/2004	1.39	1.10	5.27	4.17	979	204	20.86%
5/24/2004	1.70	1.50	7.65	6.75	1,218	143	11.76%
5/31/2004*	2.58	1.80	10.37	7.24	1,651	499	30.23%
6/7/2004*	2.59	1.41	10.19	5.55	1,622	739	45.56%
6/14/2004	2.24	1.00	8.57	3.83	1,364	755	55.36%
6/21/2004*	1.96	1.20	7.75	4.75	1,234	478	38.78%
6/28/2004	1.87	1.20	6.90	4.43	1,099	394	35.83%
7/5/2004	1.70	0.74	5.85	2.55	2,172	1,227	56.47%
7/12/2004	1.39	1.10	2.75	2.17	437	91	20.86%
7/19/2004	1.41	0.80	5.67	3.22	902	390	43.26%
7/26/2004	1.10	1.00	4.35	3.95	692	63	9.09%
8/2/2004	1.47	0.84	5.00	2.86	796	341	42.86%
8/9/2004	1.14	0.77	3.88	2.62	618	201	32.46%
8/16/2004	1.30	1.10	2.60	2.20	579	89	15.38%
8/23/2004	2.60	1.60	2.43	1.50	387	149	38.46%
8/30/2004	2.67	1.90	7.25	5.16	1,616	466	28.84%
9/9/2004	2.00	2.30	4.09	4.70	1,012	-152	-15.00%
9/13/2004	Hurricane Frances						
9/20/2004	2.89	1.47	2.89	1.47	586	288	49.13%
9/26/2004	2.40	1.50	7.14	4.46	1,326	497	37.50%
10/4/2004	Hurricane Jeanne						
10/11/2004	2.83	2.14	8.39	6.34	1,424	347	24.38%
10/18/2004	1.98	1.80	5.42	4.93	920	84	9.09%
10/25/2004	1.43	1.12	4.80	3.76	815	177	21.68%
11/1/2004	2.44	2.02	9.02	7.47	1,531	264	17.21%
11/8/2004	2.37	2.14	7.20	6.50	1,222	119	9.70%
11/15/2004	1.71	1.44	6.47	5.45	1,099	174	15.79%
11/22/2004	2.04	1.65	7.81	6.32	1,327	254	19.12%
11/29/2004	1.15	1.00	4.46	3.88	758	99	13.04%
TOTAL POR	1.94	1.39	164.18	118.21	1115	312	28.00%
TOTAL Adjusted POR	1.85	1.30	130.98	92.14	1120	332	29.66%

*Totalizer not functioning, flows calculated from average instantaneous rate
Adjusted POR excludes shaded area influenced by Hurricanes

Table 2-14: Central ATS™ Floway Total Nitrogen Loading and Removal Parameters

	Central ATS Floway Effluent						
	Total Nitrogen mg/l						
	Influent	Effluent	Influent load lbs	Effluent load lbs	Influent areal loading rate gm/m^2-yr	Effluent areal removal rate gm/m^2-yr	Percent Removal
5/17/2004	1.39	1.10	11.44	9.05	2,266	473	20.86%
5/24/2004	1.70	1.30	17.08	13.06	2,900	682	23.53%
6/1/2004	2.58	1.90	24.92	18.35	4,231	1,115	26.36%
6/7/2004	2.59	1.20	24.61	11.40	4,178	2,242	53.67%
6/14/2004*	2.24	1.34	23.64	14.14	4,014	1,613	40.18%
6/21/2004*	1.96	1.10	20.23	11.35	3,434	1,507	43.88%
6/28/2004*	1.87	1.20	18.39	11.80	3,123	1,119	35.83%
7/5/2004*	1.70	0.81	13.68	6.52	5,418	2,837	52.35%
7/12/2004	1.39	1.20	6.64	5.73	1,127	154	13.67%
7/19/2004	1.41	0.89	10.84	6.85	1,841	679	36.88%
7/26/2004	1.10	1.10	9.05	9.05	1,536	0	0.00%
8/2/2004	1.47	0.90	10.48	6.42	1,780	690	38.78%
8/9/2004	1.14	0.78	9.35	6.40	1,588	501	31.58%
8/16/2004	1.30	0.93	7.77	5.56	1,846	525	28.46%
8/23/2004	2.60	1.82	17.73	12.41	3,011	903	30.00%
8/30/2004	2.67	1.80	13.22	8.91	3,142	1,024	32.58%
9/9/2004	2.00	2.66	7.97	10.60	2,105	-695	-33.00%
9/13/2004	Hurricane Frances						
9/20/2004	2.89	2.00	16.31	11.29	3,525	1,085	30.80%
9/26/2004	2.40	1.40	12.94	7.55	2,563	1,068	41.67%
10/4/2004	Hurricane Jeanne						
10/11/2004	2.83	1.38	16.90	8.24	2,869	1,470	51.24%
10/18/2004	1.98	1.70	16.65	14.29	2,827	400	14.14%
10/25/2004	1.43	1.12	9.90	7.76	1,681	364	21.68%
11/1/2004	2.44	1.65	18.43	12.46	3,130	1,013	32.38%
11/8/2004	2.37	1.97	17.16	14.26	2,913	492	16.88%
11/15/2004	1.71	1.90	12.32	13.69	2,092	-232	-11.11%
11/22/2004	2.04	1.83	14.61	13.10	2,480	255	10.29%
11/29/2004	1.15	1.03	8.38	7.50	1,422	148	10.43%
12/5/2004	1.74	1.29	11.38	8.44	2,255	583	25.86%
TOTAL POR	1.93	1.40	402.01	286.19	2640	761	28.81%
TOTAL Adjusted POR	1.85	1.32	308.42	216.72	2428	722	29.73%

*Totalizer not functioning, flows calculated from average instantaneous rate
Adjusted POR excludes shaded area influenced by Hurricanes

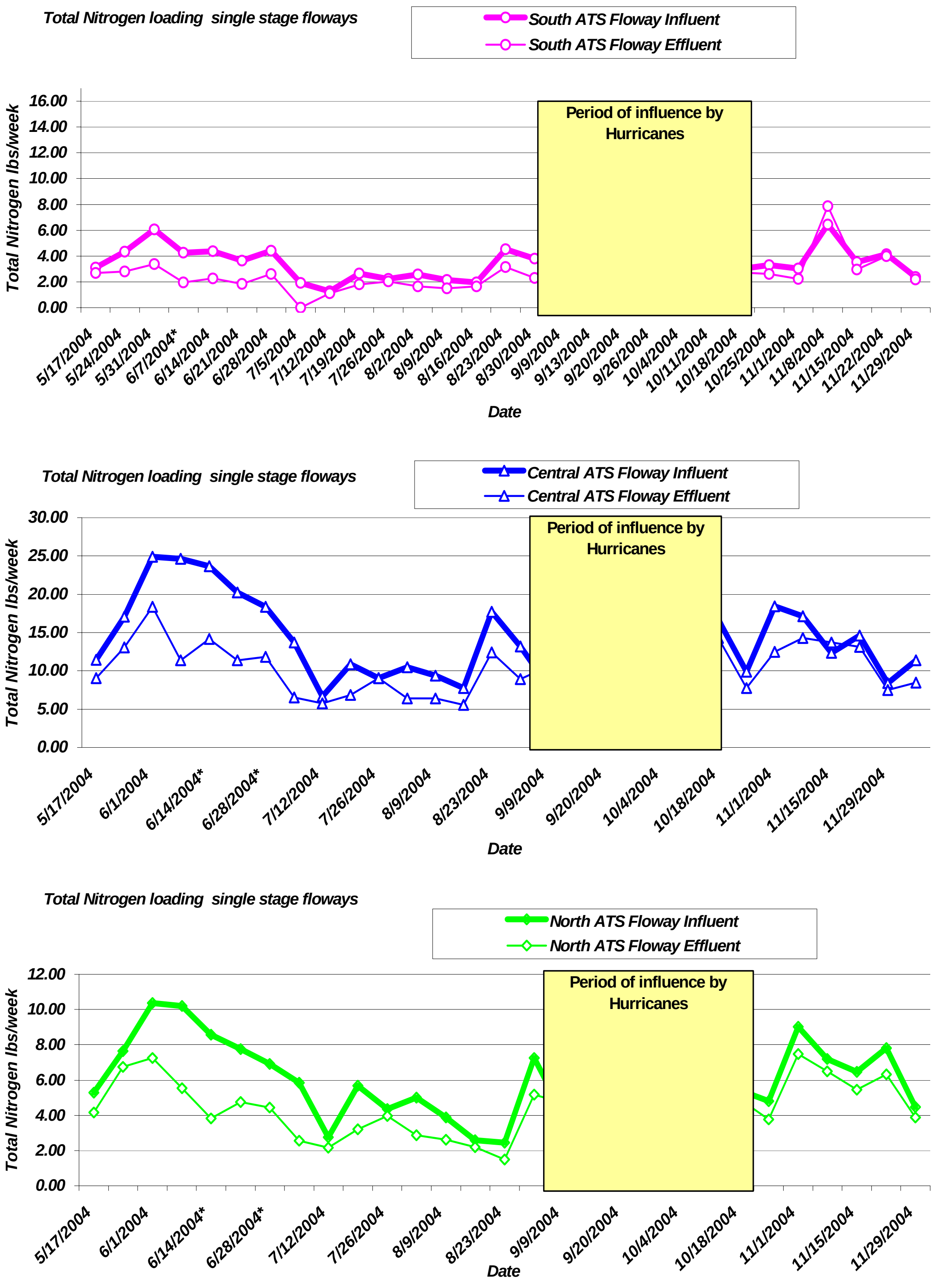


Figure 2-9: Total Nitrogen Loading and Removal May 11 December 5, 2004 single-stage ATS™ floways

SECTION 3. BIOMASS PRODUCTION AND NUTRIENT BALANCE

ANALYSIS OF BIOMASS PRODUCTION

Upon initiation of flows in May 2004, an extensive algal crop developed rather quickly. As with the larger second stage ATS™ unit operated in conjunction with the S-154 Pilot two-stage system, the predominant algae were filamentous green algae, represented largely by the genus *Cladophora, Hydrodicton,* and *Rhizoclonium*, as well as associated diatoms such as *Nitzchia* and *Navicula.* There was not a great deal of variation in species composition among the three floways, although growth typically appeared more luxuriant within the Central Floway, which had the highest LHLR. During the cooler months *Rhizoclonium* was less noticeable, with *Cladophora* becoming dominant. Also *Cyanobacteria* where observed only during the warmer period, although not widespread. The diatom species were noted to be epiphytic to the green filamentous algae.

Algae production on the single stage ATS™ units based upon recovered harvest are as shown in Table 3-1 and Figure 3-1. As projected the algae production based upon recovered harvest over the adjusted POR for the South, North and Central Floways were 11.67 dry-g/m^2-day, 11.86 dry-g/m^2-day and 14.18 dry-g/m^2-day, respectively.

Table 3-1: Harvest Algal Biomass single-stage ATS™ floways May 24 to December 2, 2004.

		ATS South			ATS Central			ATS North		
Date	**Operational days since last harvest**	**Wet Harvest lbs**	**Dry Harvest lbs**	**Estimated Dry Production g/sm-day**	**Wet Harvest lbs**	**Dry Harvest lbs**	**Estimated Dry Production g/sm-day**	**Wet Harvest lbs**	**Dry Harvest lbs**	**Estimated Dry Production g/sm-day**
5/24/2004	13	927	32.45	8.15	1,324	142.99	35.93	936	57.19	13.40
5/31/2004	7	428	23.51	10.97	493	30.54	14.25	449	18.86	8.21
6/7/2004	7	617	19.68	9.18	573	28.66	13.37	622	28.00	12.19
6/14/2004	7	865	27.33	12.75	505	22.98	10.72	973	21.31	9.28
6/21/2004	7	563	31.53	14.71	442	16.8	7.84	300	11.40	4.96
6/28/2004	7	575	29.9	13.95	556	27.24	12.71	613	33.72	14.68
7/15/2004	10	1,000	51.5	16.82	668	39.75	12.98	714	42.48	12.94
7/22/2004	7	412	22.12	10.32	160	8.93	4.17	508	31.50	13.71
7/29/2004	7	380	20.14	9.40	391	17.99	8.39	578	30.63	13.33
8/5/2004	7	185	12.03	5.61	276	11.04	5.15	860	37.84	16.47
8/19/2004	12	1,300	62.4	16.98	870	35.67	9.71	1,350	60.75	15.43
9/2/2004	12	840	33.6	9.15	680	30.6	8.33	850	29.75	7.55
9/9/2004	Power Down	System Shut Down/Crop Lost								
9/13/2004	Power Down	System Shut Down/Crop Lost								
9/23/2004	8	396	18.10	7.39	606	21.03	8.59	540	24.46	9.32
9/27/2004	Power Down	System Shut Down/Crop Lost								
10/4/2004	Power Down	System Shut Down/Crop Lost								
10/14/2004	9	446	8.92	3.24	543	11.95	4.34	311	9.64	3.26
10/21/2004	7	579	15.05	7.02	613	15.94	7.44	389	9.73	4.23
10/28/2004	7	369	34.49	16.09	406	30.21	14.10	430	25.98	11.31
11/4/2004	7	409	26.68	12.45	347	21.35	9.96	466	24.14	10.51
11/11/2004	7	412	20.31	9.48	168	7.83	3.65	296	13.42	5.84
11/18/2004	7	348	21.14	9.86	799	44.57	20.80	579	35.32	15.37
11/26/2004	8	460	21.44	8.75	1,328	55.64	22.72	802	35.13	13.38
12/2/2004	7	545	31.45	14.67	1,075	60.95	28.44	549	31.02	13.50
TOTAL Adjusted POR	146	10,634	521.70	11.67	11,059	633.74	14.18	11,875	568.44	11.86
			Max	16.98		Max	35.93		Max	16.47
			Min	3.24		Min	3.65		Min	3.26
			St. Dev.	3.75		St. Dev.	8.26		St. Dev.	3.95

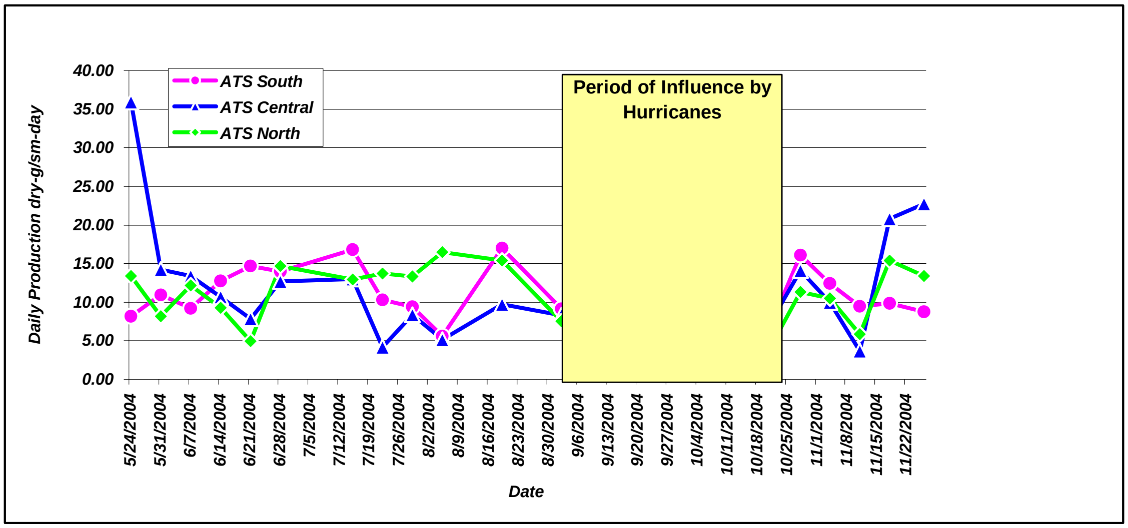


Figure 3-1: Algal Production from May 24 to December 2, 2004 Single Stage ATS™ Floways

PHOSPHORUS AND NITROGEN NUTRIENT BALANCE

A nutrient balance is developed in an effort to track movement of nutrient pollutants through the treatment process. As illustrated in Figures 3-2 and 3-3, considerable variability exists regarding quantifiable recovered pollutants on a weekly basis. While extreme variability brings into question the accuracy of the methods employed to quantify and analyze recovered solids, data from the analysis can be used to determine if system design adjustments will be beneficial to meet project objectives.

A comparison of calculated nutrient removal based upon flows and water quality to nutrient recovery accountable through algal tissue content and harvest quantities is as presented within Tables 3–2 through 3-4. Percent phosphorus harvest recovery were 101%, 62% and 37% and percent nitrogen harvest recovery were 74%, 45% and 23% through the adjusted POR for the South, North and Central Floways, respectively (Figures 3-2 and 3-3). It is noted that there is a trend towards increased accountability through harvest during the cooler periods and reduced accountability with higher hydraulic loads.

While the phosphorus removal over the adjusted POR for the South, North and Central Floways were 3.29 lbs, 5.85 lbs, and 12.40 lbs, respectively, or a ratio of 1**:**1.52**:**3.22, the algae production based upon recovered harvest, as shown in Table3-1 and Figure 3-1, over the adjusted POR for the South, North and Central Floways were 11.67 dry-g/m^2-day, 11.86 dry-g/m^2-day and 14.18 dry-g/m^2-day and respectively, or a ratio of 1**:** 1.01**:**1.22. This is suggestive that one or more of the following may apply:

1. Mechanisms other than direct plant uptake whereby phosphorus is not recovered in harvested plant tissue are involved in nutrient reduction;
2. The nutrient content of the harvested algae varies considerably within the three floways;
3. A portion of the harvest is not accounted for during collection
4. Solids recovery quantification and sampling methods are inadequate
5. Laboratory tissue analyses are inadequate.

Mechanisms other than plant uptake that can be involved in phosphorus removal would be precipitation; adsorption/desorption; and emigration through predation and larval emergence. As there is very limited storage space for accumulation of precipitants not associated with recovered biomass, it seems unlikely that internal storage of any consequence would occur, and if it did, it would be reversible and most likely ephemeral. Emigration is possible through emergence of insect larvae, or predation by wading birds, but there is no evidence that this occurs with preference to the Central Floway.

Because some loss of nitrogen through mechanisms such as denitrification is anticipated, a close balance between harvested nitrogen and calculated nitrogen removed through water quality and flows is not necessarily expected. However, a closer match is projected for phosphorus, and this is noted within the South single stage floway, which received the lowest LHLR.

Table 3-2: Nutrient accountability South ATS™ Floway

		ATS South								
Date	Operational days since last harvest	Dry Harvest lbs	Biomass Phosphorus Content % dw	Biomass Nitrogen Content % dw	Phosphorus Accountable in Harvest lbs	Phosphorus Removed per Water Quality lbs	Percent Harvest Recovery	Nitrogen Accountable in Harvest lbs	Nitrogen Removed per Water Quality lbs	Percent Harvest Recovery
5/24/2004	13	32.45	0.50%	3.02%	0.16	0.44	37.12%	0.98	1.96	49.96%
5/31/2004	7	23.51	0.50%	3.02%	0.12	0.41	28.55%	0.71	2.68	26.47%
6/7/2004	7	19.68	0.50%	3.02%	0.10	0.19	52.14%	0.59	2.28	26.05%
6/14/2004	7	27.33	0.50%	3.02%	0.14	0.19	71.99%	0.83	2.13	38.69%
6/21/2004	7	31.53	0.50%	3.02%	0.16	0.16	101.35%	0.95	1.78	53.56%
6/28/2004	7	29.9	0.50%	3.02%	0.15	0.17	89.13%	0.90	1.82	49.64%
7/15/2004	10	51.5	0.48%	3.17%	0.25	0.12	214.71%	1.63	2.10	77.91%
7/22/2004	7	22.12	0.48%	3.17%	0.11	0.01	1897.80%	0.70	0.84	83.56%
7/29/2004	7	20.14	0.62%	2.90%	0.12	0.09	146.62%	0.58	0.20	288.04%
8/5/2004	7	12.03	0.62%	2.90%	0.07	0.08	89.09%	0.35	0.92	37.74%
8/19/2004	12	62.4	0.62%	2.90%	0.39	0.13	290.39%	1.81	0.99	183.29%
9/2/2004	12	33.6	1.03%	3.38%	0.35	0.79	44.02%	1.14	2.88	39.38%
9/9/2004	Power Down	System Shut Down/Crop Lost								
9/13/2004	Power Down	System Shut Down/Crop Lost								
9/20/2004	8	18.10	1.03%	3.38%	0.19	0.17	110.60%	0.61	1.70	36.02%
9/26/2004	Power Down	System Shut Down/Crop Lost								
10/4/2004	Power Down	System Shut Down/Crop Lost								
10/11/2004	9	8.92	1.03%	3.38%	0.09	-0.10	-95.91%	0.30	2.86	10.55%
10/18/2004	7	15.05	1.03%	3.38%	0.16	-0.06	-263.46%	0.51	0.27	187.32%
10/25/2004	7	34.49	0.73%	2.56%	0.25	0.16	156.41%	0.88	0.69	127.99%
11/1/2004	7	26.68	0.73%	2.56%	0.19	0.07	261.50%	0.68	0.82	83.37%
11/8/2004	7	20.31	1.01%	3.45%	0.21	0.08	251.06%	0.70	-1.42	-49.42%
11/15/2004	7	21.14	1.01%	3.45%	0.21	0.10	206.06%	0.73	0.58	125.54%
11/22/2004	8	21.44	1.01%	3.45%	0.22	0.04	534.32%	0.74	0.14	520.86%
11/29/2004	7	31.45	1.01%	3.45%	0.32	0.25	128.64%	1.08	0.16	658.36%
TOTAL POR	170	366.19	0.58%	3.05%	2.11	2.76	76.38%	11.18	20.59	54.29%
Adjusted POR	146	521.70	0.67%	3.07%	3.51	3.47	101.13%	15.99	21.57	74.16%

Table 3-3: Nutrient accountability North ATS™ Floway

		ATS North								
Date	Operational days since last harvest	Dry Harvest lbs	Biomass Phosphorus Content % dw	Biomass Nitrogen Content % dw	Phosphorus Accountable in Harvest lbs	Phosphorus Removed per Water Quality lbs	Percent Recovery	Nitrogen Accountable in Harvest lbs	Nitrogen Removed per Water Quality lbs	Percent Recovery
5/24/2004	13	57.19	0.60%	3.06%	0.34	0.58	59.45%	1.75	2.00	87.51%
5/31/2004	7	18.86	0.60%	3.06%	0.11	0.66	17.06%	0.58	3.14	18.40%
6/7/2004	7	28.00	0.60%	3.06%	0.17	0.33	50.25%	0.86	4.64	18.46%
6/14/2004	7	21.31	0.60%	3.06%	0.13	0.34	37.14%	0.65	4.74	13.75%
6/21/2004	7	11.40	0.60%	3.06%	0.07	0.30	22.75%	0.35	3.01	11.60%
6/28/2004	7	33.72	0.60%	3.06%	0.20	0.20	99.67%	1.03	2.47	41.73%
7/15/2004	10	42.48	0.42%	3.14%	0.18	0.31	56.88%	1.33	3.88	34.42%
7/22/2004	7	31.50	0.42%	3.14%	0.13	0.06	205.67%	0.99	2.45	40.33%
7/29/2004	7	30.63	0.50%	2.91%	0.15	0.18	84.25%	0.89	0.40	225.56%
8/5/2004	7	37.84	0.50%	2.91%	0.19	0.34	54.84%	1.10	2.14	51.41%
8/19/2004	12	60.75	0.50%	2.91%	0.30	0.16	193.25%	1.77	1.66	106.50%
9/2/2004	12	29.75	1.06%	3.23%	0.32	0.88	35.94%	0.96	3.03	31.73%
9/9/2004	Power Down									
9/13/2004	Power Down									
9/20/2004	8	24.46	1.06%	3.23%	0.26	0.32	80.27%	0.79	1.42	55.64%
9/26/2004	Power Down									
10/4/2004	Power Down									
10/11/2004	9	9.64	1.06%	3.23%	0.10	-0.47	-21.96%	0.31	2.05	15.23%
10/18/2004	7	9.73	1.06%	3.23%	0.10	-0.11	-96.60%	0.31	0.49	63.78%
10/25/2004	7	25.98	0.73%	3.05%	0.19	0.34	56.50%	0.79	1.04	76.15%
11/1/2004	7	24.14	0.73%	3.05%	0.18	0.33	52.97%	0.74	1.55	47.42%
11/8/2004	7	13.42	0.94%	3.57%	0.13	0.24	51.92%	0.48	0.70	68.59%
11/15/2004	7	35.32	0.94%	3.57%	0.33	0.30	109.63%	1.26	1.02	123.37%
11/22/2004	8	35.13	0.94%	3.57%	0.33	0.31	107.78%	1.25	1.49	83.97%
11/29/2004	7	31.02	0.94%	3.57%	0.29	0.27	107.30%	1.11	0.58	190.17%
TOTAL	170	612.27	0.69%	3.15%	4.21	5.91	71.21%	19.31	43.90	43.98%
Adjusted POR	146	568.44	0.66%	3.15%	3.74	6.15	60.78%	17.89	39.94	44.79%

Table 3-4: Nutrient accountability Central ATS™ Floway

		ATS Central								
Date	Operational days since last harvest	Dry Harvest lbs	Biomass Phosphorus Content % dw	Biomass Nitrogen Content % dw	Phosphorus Accountable in Harvest lbs	Phosphorus Removed per Water Quality lbs	Percent Recovery	Nitrogen Accountable in Harvest lbs	Nitrogen Removed per Water Quality lbs	Percent Recovery
5/24/2004	13	142.99	0.58%	2.97%	0.83	1.42	58.23%	4.25	6.41	66.30%
5/31/2004	7	30.54	0.58%	2.97%	0.18	1.59	11.12%	0.91	6.57	13.81%
6/7/2004	7	28.66	0.58%	2.97%	0.17	1.09	15.22%	0.85	13.21	6.45%
6/14/2004	7	22.98	0.58%	2.97%	0.13	0.74	18.04%	0.68	9.50	7.18%
6/21/2004	7	16.8	0.58%	2.97%	0.10	0.60	16.28%	0.50	8.87	5.62%
6/28/2004	7	27.24	0.58%	2.97%	0.16	0.43	36.51%	0.81	6.59	12.28%
7/15/2004	10	39.75	0.49%	3.17%	0.19	0.54	36.07%	1.26	8.07	15.62%
7/22/2004	7	8.93	0.49%	3.17%	0.04	0.02	189.64%	0.28	4.00	7.08%
7/29/2004	7	17.99	0.72%	3.22%	0.13	0.25	50.80%	0.58	0.00	NA
8/5/2004	7	11.04	0.72%	3.22%	0.08	0.19	41.29%	0.36	4.06	8.75%
8/19/2004	12	35.67	0.72%	3.22%	0.26	0.44	58.12%	1.15	5.16	22.24%
9/2/2004	12	30.6	1.33%	3.82%	0.41	2.64	15.44%	1.17	9.63	12.14%
9/9/2004	Power Down	System Shut Down/Crop Lost								
9/13/2004	Power Down	System Shut Down/Crop Lost								
9/20/2004	8	21.03	1.33%	3.82%	0.28	0.64	43.85%	0.80	5.02	15.99%
9/26/2004	Power Down	System Shut Down/Crop Lost								
10/4/2004	Power Down	System Shut Down/Crop Lost								
10/11/2004	9	11.95	1.33%	3.82%	0.16	-0.94	-16.95%	0.46	8.66	5.27%
10/18/2004	7	15.94	1.33%	3.82%	0.21	-0.33	-64.64%	0.61	2.35	25.86%
10/25/2004	7	30.21	0.77%	2.82%	0.23	0.55	41.99%	0.85	2.15	39.68%
11/1/2004	7	21.35	0.77%	2.82%	0.16	0.68	24.18%	0.60	5.97	10.09%
11/8/2004	7	7.83	0.88%	4.23%	0.07	0.29	23.80%	0.33	2.90	11.44%
11/15/2004	7	44.57	0.88%	4.23%	0.39	0.29	136.07%	1.89	-1.37	-137.70%
11/22/2004	8	55.64	0.88%	4.23%	0.49	0.29	170.96%	2.35	1.50	156.52%
11/29/2004	7	60.95	0.88%	4.23%	0.54	0.36	147.30%	2.58	0.87	295.01%
TOTAL POR	170	682.65	0.76%	3.41%	5.21	11.80	44.12%	23.26	110.12	21.12%
Adjusted POR	146	633.74	0.72%	3.38%	4.56	12.43	36.66%	21.39	94.08	22.74%

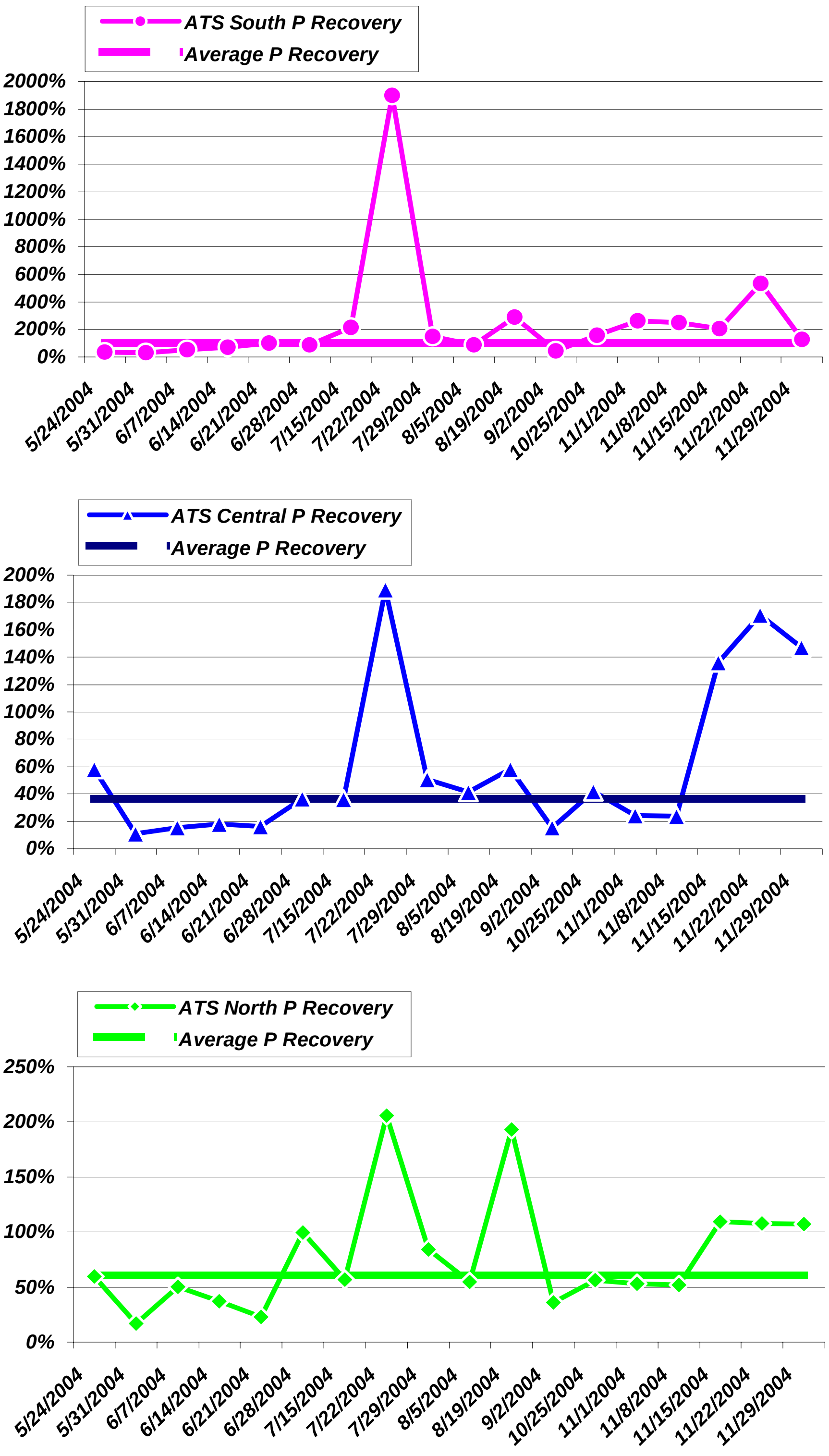
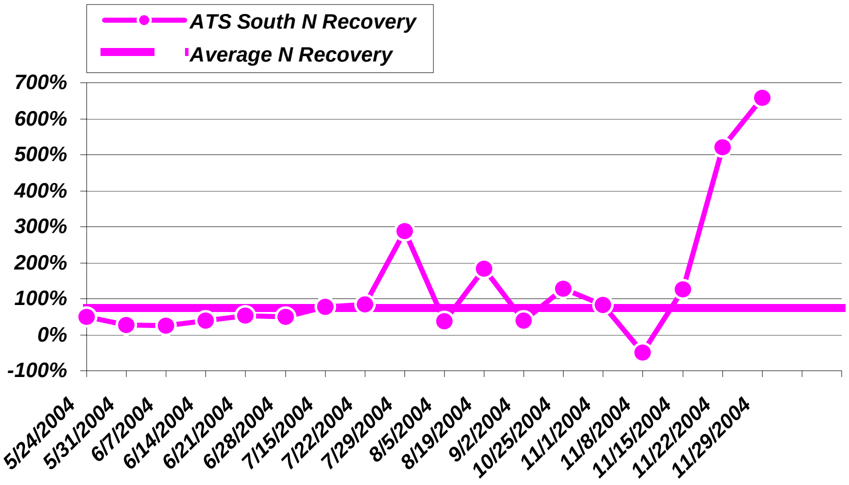
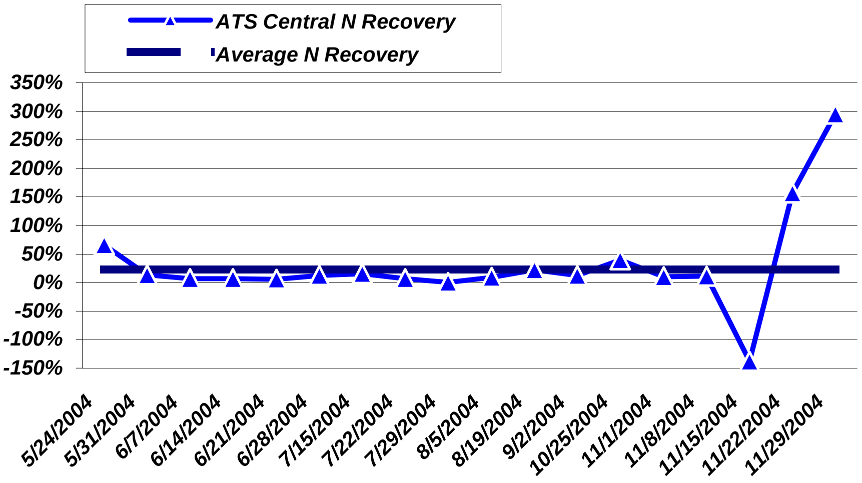


Figure 3-2: Weekly and average harvest accountability as % of total phosphorus mass removal for the period of record.





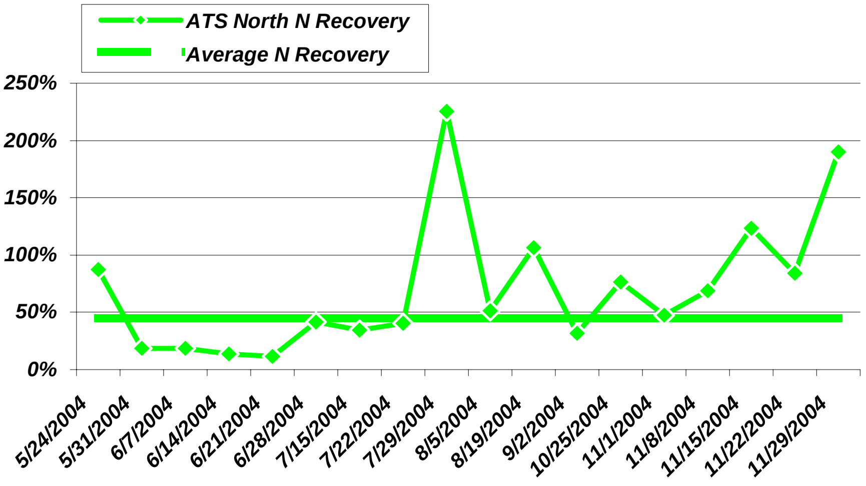


Figure 3-3: Weekly and average harvest accountability as % of total nitrogen mass removal for the period of record.

In an effort to review in greater detail those factors that may affect accuracy as it applies to quantification of recovered pollutants, HydroMentia investigated the possibility that nutrient content of the harvested algae varies considerably within the three floways (Item 2). This discussion is provided in the section titled “Floway Sample Location Impacts”. In addition, in the section following titled “Harvest Induced Sloughing”, an analysis has been conducted to determine if a portion of the harvest is not accounted for during collection (Item 3).

Floway Sample Location Impacts

The possibility that nutrient content of the algae tissue along the floway path could be impacted by the variation in velocity and linear hydraulic loading rate was investigated during the harvesting sequences on 10/28/2004, 11/4/2004; 11/11/2004; and 11/18/2004 when removal of biomass was done in five equally sized segments (60 ft) down each floway (Segment 1 was the closest to the surger influent). Individual samples were taken from each segment and delivered to Midwest Laboratories for nutrient analysis. The results, as summarized in Tables 3-5 through 3-8, provide indication that there is no clear trend either in production rates or tissue nutrient content with distance down the ATS™ floway, based upon captured biomass for the period of investigation. Furthermore based upon captured biomass, there is no clear, dramatic production or nutrient content advantage associated with the higher LHLR, even though there is a distinct advantage associated with areal removal rates of both nitrogen and phosphorus, as noted in subsequent sections of this text.

Table 3-5: Discrete Harvesting Results 10/28/04.

South Floway		**Wet Harvest lbs**	**Dry Harvest lbs**	**Phosphorus content % dw**	**Nitrogen content % dw**	**Phosphorus lbs**	**Nitrogen lbs**
Segment 1	10/28/2004	82.15	6.16	0.69%	2.40%	0.04	0.15
Segment 2	10/28/2004	42.00	3.36	0.74%	2.62%	0.02	0.09
Segment 3	10/28/2004	67.15	5.71	0.75%	2.66%	0.04	0.15
Segment 4	10/28/2004	59.90	4.67	0.76%	2.75%	0.04	0.13
Segment 5	10/28/2004	117.65	14.60	0.71%	2.38%	0.10	0.35
Total		**368.85**	**34.50**	**0.73%**	**2.56%**	**0.25**	**0.86**
Central Floway							
Segment 1	10/28/2004	121.60	8.84	0.85%	3.06%	0.08	0.27
Segment 2	10/28/2004	93.80	6.38	0.70%	2.69%	0.04	0.17
Segment 3	10/28/2004	37.60	2.12	0.80%	3.09%	0.02	0.07
Segment 4	10/28/2004	48.80	3.31	0.75%	2.58%	0.02	0.09
Segment 5	10/28/2004	103.90	9.56	0.76%	2.70%	0.07	0.26
Total		**405.70**	**30.21**	**0.77%**	**2.82%**	**0.23**	**0.85**
North Floway							
Segment 1	10/28/2004	212.25	12.37	0.73%	3.12%	0.09	0.39
Segment 2	10/28/2004	91.60	5.33	0.74%	3.17%	0.04	0.17
Segment 3	10/28/2004	41.60	2.28	0.72%	3.39%	0.02	0.08
Segment 4	10/28/2004	10.40	0.65	0.72%	2.91%	0.00	0.02
Segment 5	10/28/2004	73.95	5.35	0.70%	2.67%	0.04	0.14
Total		**429.80**	**25.98**	**0.72%**	**3.05%**	**0.19**	**0.79**

Table 3-6: Discrete Harvesting Results 11/4/04. Total for mass is summed, total for percent represents mean of all 5 segment samples.

South Floway		**Wet Harvest lbs**	**Dry Harvest lbs**	**Phosphorus content % dw**	**Nitrogen content % dw**	**Phosphorus lbs**	**Nitrogen lbs**
Segment 1	11/4/2004	32.50	1.92	0.69%	2.40%	0.01	0.05
Segment 2	11/4/2004	76.00	5.41	0.74%	2.62%	0.04	0.14
Segment 3	11/4/2004	89.95	6.12	0.75%	2.66%	0.05	0.16
Segment 4	11/4/2004	78.70	4.58	0.76%	2.75%	0.03	0.13
Segment 5	11/4/2004	131.40	8.70	0.71%	2.38%	0.06	0.21
Total		**408.55**	**26.73**	**0.73%**	**2.56%**	**0.20**	**0.68**
Central Floway							
Segment 1	11/4/2004	41.30	1.90	0.85%	3.06%	0.02	0.06
Segment 2	11/4/2004	73.50	4.26	0.70%	2.69%	0.03	0.11
Segment 3	11/4/2004	83.00	5.40	0.80%	3.09%	0.04	0.17
Segment 4	11/4/2004	74.35	4.76	0.75%	2.58%	0.04	0.12
Segment 5	11/4/2004	81.00	5.21	0.76%	2.70%	0.04	0.14
Total		**353.15**	**21.53**	**0.77%**	**2.82%**	**0.16**	**0.60**
North Floway							
Segment 1	11/4/2004	91.35	4.36	0.73%	3.12%	0.03	0.14
Segment 2	11/4/2004	88.30	4.50	0.74%	3.17%	0.03	0.14
Segment 3	11/4/2004	114.71	5.69	0.72%	3.39%	0.04	0.19
Segment 4	11/4/2004	81.00	4.37	0.72%	2.91%	0.03	0.13
Segment 5	11/4/2004	90.20	5.21	0.70%	2.67%	0.04	0.14
Total		**465.56**	**24.13**	**0.72%**	**3.05%**	**0.17**	**0.74**

Table 3-7: Discrete Harvesting Results 11/11/04. Total for mass is summed, total for percent represents mean of all 5 segment samples.

South Floway		**Wet Harvest lbs**	**Dry Harvest lbs**	**Phosphorus content % dw**	**Nitrogen content % dw**	**Phosphorus lbs**	**Nitrogen lbs**
Segment 1	11/11/2004	64.45	3.42	0.94%	3.55%	0.03	0.12
Segment 2	11/11/2004	83.50	2.89	1.02%	3.38%	0.03	0.10
Segment 3	11/11/2004	75.70	3.79	1.00%	3.31%	0.04	0.13
Segment 4	11/11/2004	85.00	4.32	1.06%	3.73%	0.05	0.16
Segment 5	11/11/2004	103.00	5.90	1.03%	3.26%	0.06	0.19
Total		**411.65**	**20.32**	**1.01%**	**3.45%**	**0.21**	**0.70**
Central Floway							
Segment 1	11/11/2004	24.00	0.96	0.82%	4.82%	0.01	0.05
Segment 2	11/11/2004	40.80	1.77	0.83%	3.30%	0.01	0.06
Segment 3	11/11/2004	41.25	1.57	0.94%	4.13%	0.01	0.06
Segment 4	11/11/2004	32.25	2.09	0.91%	4.08%	0.02	0.09
Segment 5	11/11/2004	29.20	1.43	0.90%	4.82%	0.01	0.07
Total		**167.50**	**7.82**	**0.88%**	**4.23%**	**0.07**	**0.32**
North Floway							
Segment 1	11/11/2004	32.20	1.06	0.98%	2.96%	0.01	0.03
Segment 2	11/11/2004	66.70	2.87	0.92%	3.31%	0.03	0.09
Segment 3	11/11/2004	78.70	3.51	1.00%	3.14%	0.04	0.11
Segment 4	11/11/2004	67.00	3.06	0.96%	3.49%	0.03	0.11
Segment 5	11/11/2004	51.60	2.92	0.84%	2.94%	0.02	0.09
Total		**296.20**	**13.42**	**0.94%**	**3.17%**	**0.13**	**0.43**

Table 3-8: Discrete Harvesting Results 11/18/04. Total for mass is summed, total for percent represents mean of all 5 segment samples.

South Floway		Wet Harvest lbs	Dry Harvest lbs	Phosphorus content % dw	Nitrogen content % dw	Phosphorus lbs	Nitrogen lbs
Segment 1	11/18/2004	81.00	5.25	0.94%	3.55%	0.05	0.19
Segment 2	11/18/2004	68.00	4.80	1.02%	3.38%	0.05	0.16
Segment 3	11/18/2004	77.00	4.77	1.00%	3.31%	0.05	0.16
Segment 4	11/18/2004	71.00	3.55	1.06%	3.73%	0.04	0.13
Segment 5	11/18/2004	51.30	2.80	1.03%	3.26%	0.03	0.09
Total		**348.30**	**21.17**	**1.01%**	**3.45%**	**0.21**	**0.73**
Central Floway							
Segment 1	11/18/2004	137.00	7.48	0.82%	4.82%	0.06	0.36
Segment 2	11/18/2004	203.00	14.96	0.83%	3.30%	0.12	0.49
Segment 3	11/18/2004	217.00	9.53	0.94%	4.13%	0.09	0.39
Segment 4	11/18/2004	130.00	8.27	0.91%	4.08%	0.08	0.34
Segment 5	11/18/2004	112.00	4.33	0.90%	4.82%	0.04	0.21
Total		**799.00**	**44.57**	**0.88%**	**4.23%**	**0.39**	**1.79**
North Floway							
Segment 1	11/18/2004	142.95	10.24	0.98%	2.96%	0.10	0.30
Segment 2	11/18/2004	84.30	4.85	0.92%	3.31%	0.04	0.16
Segment 3	11/18/2004	123.00	7.49	1.00%	3.14%	0.07	0.24
Segment 4	11/18/2004	130.20	7.06	0.96%	3.49%	0.07	0.25
Segment 5	11/18/2004	99.00	5.69	0.84%	2.94%	0.05	0.17
Total		**579.45**	**35.33**	**0.94%**	**3.17%**	**0.34**	**1.11**

Harvest Induced Sloughing

It has been considered possible that a fraction of the unaccountable phosphorus may be associated with sloughing of unicellular algae, small cellular aggregates, (e.g. diatoms and desmids) and filament fragments that escape during harvesting or biomass recovery. Because of the brief period of this discharge, these loads might escape the effluent water quality sampling sequence. This possibility of a "harvest induced sloughing" is supported to an extent by the percentage of the algae biomass which escaped the harvest rake within the larger two stage ATS™ - WHS™ operation. This was discussed within the recent S-154 Pilot Q5 report, in which it was noted that the amount of algae escaping the harvest rake and being either captured by the microscreen, or diverted, was approximately equal to that being captured by the rake.

Recognizing this, some effort was made during harvest of the single-stage floways to reduce "harvest induced sloughing" percentage by terminating flow during the short harvest period. Based on this protocol, following harvest, when the flow was returned, it was noted that some turbidity persisted within the effluent, for a brief period, typically less than 60 minutes. To quantify the characteristics of these harvest flows, a single grab sample of this turbid flow was taken from the Central Floway, and was analyzed for total phosphorus. It was found to contain 1.70 mg/l total phosphorus. Over a 60-minute period at 100 gpm, assuming this represents a mean concentration during the "harvest induced sloughing" period, about 0.09 lb/week of phosphorus, when harvested once weekly, would be lost through the Central Floway effluent, or a total of perhaps 1.98 pounds over the entire adjusted POR. This would represent about 43% of the phosphorus accounted for in the collected harvest associated with the Central Floway, or an additional 16% of the calculated removed phosphorus, which would increase phosphorus accountability to 53%.

It is of note that this would be an unmonitored source that could likely be directly influenced by flow velocity, i.e. increased flushing of loose solids following harvest. It is also possible that the population of diatoms and desmids may be higher in systems with higher LHLR values, at least during the warmer months. This may account for the appearance of more luxuriant growth, even though the captured harvest was similar to the other floways.

Based on the information collected to date, to assure that "harvest induced sloughing" is recovered from the ATS™ unit, system design and operational strategy should include provisions for the harvest flow to be bypassed to a holding pond, with the supernatant to eventually be re-introduced into the treatment system, with the solids being settled, recovered and ultimately diverted to the compost operation.

The hypothesis of a significant "harvest induced sloughing" can be examined further by considering the change in available carbon through each floway. The diurnal variability down the ATS™ in the effluent pH is associated with the consumption of carbon dioxide, bicarbonate and carbonate during photosynthesis by the algae community. This is a well-documented phenomenon that results in a shift in the alkalinity species with an increase in hydroxide (OH^-) and a decrease in bicarbonate (HCO_3^-) alkalinity as pH rises. As the algae production increases carbon consumption, there is an imposition upon carbonate ($CO_3^=$) to the extent that when the pH reaches about 10.5 the carbonate alkalinity will begin to decline and hydroxide alkalinity becomes predominant. A pH of about 9.5 represents the approximate point at which hydroxide alkalinity begins a dramatic increase and bicarbonate declines, and accordingly the carbon availability declines. This may also be the point at which pH influences production and viability of many algae species.

Studies on phytoplankton productivity in the Great Lakes related pH, alkalinity, and available carbon, based upon disassociation equations as noted in Figure 3-3 (Saunders et al., 1962). For approximation purposes, at pH between 6.0 and 7.0, this curve is closely represented by the equation $y = 300/e^x$, where y is the fraction of alkalinity as available carbon, and x is pH. For pH higher than 7.0 to 9.4 this relationship becomes more linear, and for approximation purposes may be represented by the equation $y = 0.53 – 0.033x$, with y and x as identified previously. Considering this, the pH shift from influent and effluent, and the alkalinity for this period, the amount of consumed carbon can be estimated, assuming no significant contribution from the atmosphere. This carbon consumption estimate can then be used to identify the general magnitude of algae production associated with this consumption, and accordingly to the measured algae production, and the necessary algae production required to satisfy the observed phosphorus removal. These calculations are noted within the spreadsheet included as Tables 3-9 through 3-11, and the graphic representation as Figures 3-4 through 3-6. It is assumed the algae tissue is 33% carbon by dry weight.

It is important to view the carbon consumption projections as a representation of nighttime Gross Primary Production (GPP) and daytime Net Primary Production (NPP). As carbon fixation through photosynthesis occurs only during the daylight hours, the projections were done with consideration of the length of the photoperiod. Because both photosynthesis (carbon fixation) and respiration (carbon dioxide release) occur during the daytime, the carbon consumption as shown may be considered an approximation of diurnal NPP, or the difference between carbon fixation and carbon release. However, what are not shown are the general effects of nighttime respiration, and the attendant carbon dioxide release, which would need to be subtracted from the projections shown, to be a true NPP. As the carbon consumption projections are typically higher than even the production numbers based upon phosphorus uptake, there is some support given to the thought that actual production is higher than what was recovered by harvest, and that this difference may be partly due to losses during the "harvest induced sloughing". In viewing these comparisons, it is important to recognize that the carbon consumption projections represent a rough estimate, to be used as only a general indicator of production trends. Interchange with the atmosphere, as well as uncertainties associated with nighttime respiration have not been seriously examined during the development of these projections, as this would require extensive research well beyond the scope of this project. As noted however, the approximations do provide some helpful insight into this issue, and also demonstrates the importance of carbon dioxide within these types of systems, particularly when alkalinities are low. The issue of the potential of carbon influence upon productivity, and hence nutrient uptake are discussed in subsequent sections of this text.

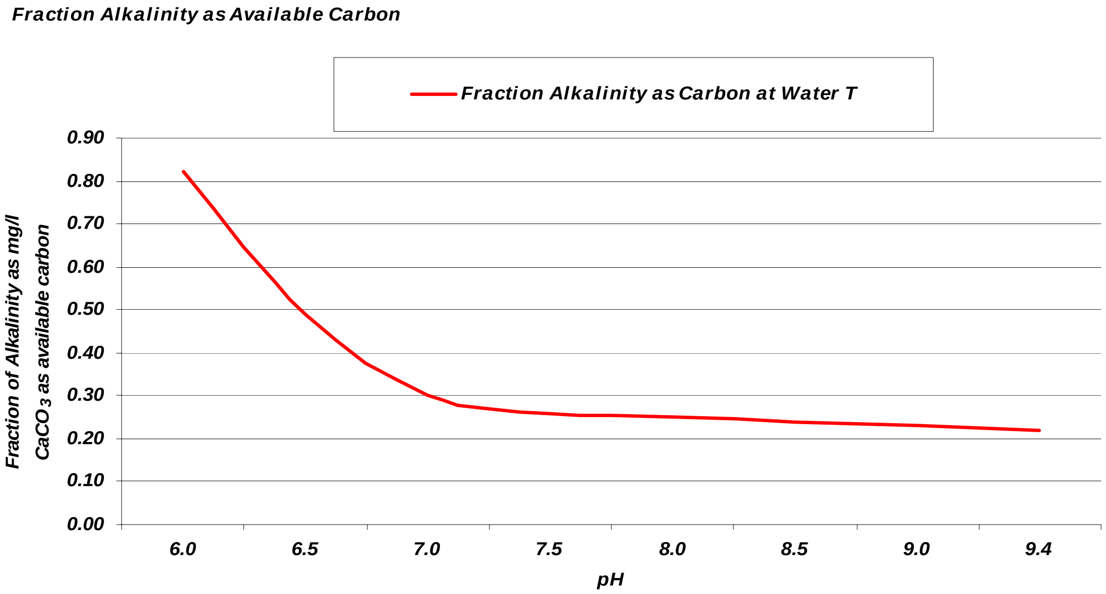


Figure 3-3: Relationship between Available Carbon, pH and Alkalinity from Saunders et al. (1962)

Table 3-9: Carbon consumption based algal production estimates compared to actual harvest data and phosphorus uptake based production projections South single-stage ATS™ floway

Date	Alkalinity	Influent pH	Effluent pH*	Phosphorus Removed lbs	Algae Tissue Phosphorus content %dw	Influent Available Carbon Estimated mg/l	Effluent Available Carbon Estimated mg/l	Photoperiod % of diurnal cycle	Period Flow Gallons	Estimated Consumed Carbon lbs	Estimated Algal Production dry weight lbs from carbon consumption	Estimated Algal Production dry weight lbs from phosphorus removal	Captured Algal Production from harvest dry weight lbs
5/24/2004	36	6.75	8.08	0.44	0.50%	13.83	9.48	49.37%	574,810	10.28	31.16	87.40	32.45
5/31/2004	33	6.34	8.21	0.41	0.50%	19.14	8.55	49.97%	282,112	12.44	37.70	82.35	23.51
6/7/2004	26	6.33	7.94	0.19	0.50%	15.24	6.97	50.57%	196,784	6.86	20.79	37.75	19.68
6/14/2004	34	6.43	8.27	0.19	0.50%	17.98	8.74	51.17%	234,645	9.25	28.03	37.96	27.33
6/21/2004	32	6.34	8.38	0.16	0.50%	18.56	8.12	51.77%	222,036	10.02	30.35	31.11	31.53
6/28/2004	33	6.50	9.09	0.17	0.50%	16.23	7.59	52.37%	283,278	10.69	32.39	33.55	29.90
7/15/2004	36	6.90	9.01	0.12	0.48%	11.90	8.38	52.97%	325,000	5.06	15.33	23.99	51.50
7/22/2004	42	7.29	8.78	0.01	0.48%	12.16	10.10	53.57%	215,000	1.98	5.99	1.17	22.12
7/29/2004	37	6.28	8.85	0.09	0.62%	22.68	8.81	54.17%	185,000	11.59	35.13	13.74	20.14
8/5/2004	39	7.08	8.38	0.08	0.62%	11.55	9.88	53.87%	200,540	1.51	4.57	13.50	12.03
8/19/2004	44	6.45	7.84	0.13	0.62%	22.81	11.94	53.57%	201,673	9.80	29.69	21.49	62.40
9/2/2004	68	6.59	8.04	0.79	1.03%	30.72	18.01	52.37%	316,000	17.55	53.17	76.33	33.6
10/25/2004	40	6.24	8.71	0.16	0.73%	25.58	9.71	51.17%	275,731	18.68	56.59	22.05	34.49
11/1/2004	40	7.17	8.92	0.07	0.73%	11.74	9.42	49.97%	148,838	1.43	4.35	10.20	26.68
11/8/2004	42	6.26	9.06	0.08	1.01%	26.33	9.70	48.77%	326,566	22.08	66.92	8.09	20.31
11/15/2004	44	6.34	8.97	0.10	1.01%	25.46	10.30	47.57%	248,487	14.95	45.29	10.26	21.14
11/22/2004	45	6.53	8.98	0.04	1.01%	21.53	10.51	46.37%	242,969	10.36	31.39	4.01	21.44
11/29/2004	35	6.51	8.63	0.25	1.01%	17.09	8.59	45.17%	246,728	7.90	23.95	24.45	31.45
										Totals	**552.78**	**539.38**	**521.70**

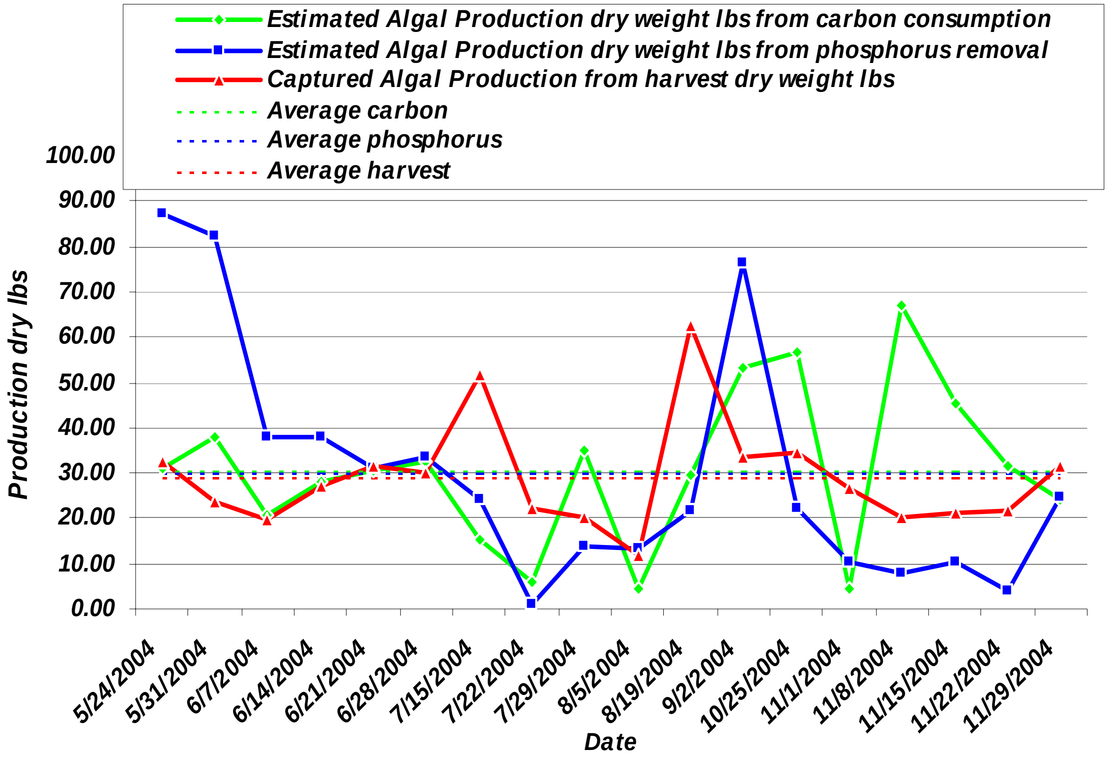


Figure 3-4: Trends in carbon consumption based algal production estimates compared to actual harvest and phosphorus uptake based production projections South single-stage ATS™ floway

Table 3-10: Carbon consumption based algal production estimates compared to actual harvest data and phosphorus uptake based production projections Central single-stage ATS™ floway

Date	Alkalinity	Influent pH	Effluent pH*	Phosphorus Removed lbs	Algae Tissue Phosphorus content %dw	Influent Available Carbon Estimated mg/l	Effluent Available Carbon Estimated mg/l	Period Flow Gallons	Photoperiod % of diurnal cycle	Estimated Consumed Carbon lbs	Estimated Algal Production dry weight lbs from carbon consumption	Estimated Algal Net Production dry weight lbs from phosphorus removal	Captured Algal Net Production from harvest dry weight lbs
5/24/2004	36	6.75	7.85	1.42	0.58%	13.86	9.75	2,191,418	56.69%	42.54	125.12	245.58	142.992
5/31/2004	33	6.34	7.72	1.59	0.58%	19.14	9.08	1,157,989	56.69%	55.06	161.93	274.74	30.54
6/7/2004	26	6.33	7.55	1.09	0.58%	15.24	7.30	1,139,115	57.42%	43.28	127.31	188.37	28.66
6/14/2004	34	6.43	7.96	0.74	0.58%	17.98	9.09	1,265,598	57.42%	53.90	158.52	127.39	22.98
6/21/2004	32	6.34	8.36	0.60	0.58%	18.56	8.14	1,237,320	57.42%	61.78	181.71	103.19	16.8
6/28/2004	33	6.50	8.97	0.43	0.58%	16.23	7.72	1,179,360	57.42%	48.08	141.41	74.62	27.24
7/15/2004	36	6.90	8.62	0.54	0.49%	11.90	8.84	2,041,446	56.79%	29.59	87.04	110.19	39.75
7/22/2004	42	6.28	8.60	0.02	0.49%	25.74	10.34	949,603	56.79%	69.26	203.72	4.71	8.93
7/29/2004	37	7.29	8.65	0.25	0.72%	10.71	9.05	929,894	56.79%	7.31	21.51	35.41	17.99
8/5/2004	39	6.45	7.73	0.19	0.72%	20.22	10.73	972,818	53.10%	40.89	120.26	26.74	11.04
8/19/2004	44	6.56	8.42	0.44	0.72%	20.43	11.09	1,474,487	53.10%	60.99	179.39	61.37	35.67
9/2/2004	68	6.29	8.70	2.64	1.33%	41.37	16.51	1,828,286	49.21%	186.51	548.55	198.18	30.6
10/25/2004	40	6.24	8.70	0.55	0.77%	25.58	9.71	830,325	47.21%	51.88	152.59	71.95	30.21
11/1/2004	40	7.17	8.91	0.68	0.77%	11.74	9.44	905,817	44.50%	7.73	22.74	88.30	21.35
11/8/2004	42	6.26	9.05	0.29	0.88%	26.33	9.72	867,933	44.50%	53.49	157.32	32.90	7.83
11/15/2004	44	6.34	9.06	0.29	0.88%	25.46	10.17	864,060	44.50%	49.04	144.25	32.76	44.57
11/22/2004	45	6.53	9.01	0.29	0.88%	21.53	10.47	858,542	44.50%	35.24	103.66	32.55	55.64
11/29/2004	35	6.51	8.63	0.36	0.88%	17.09	8.58	873,224	44.50%	27.56	81.07	41.38	60.95
										Total	2718.09	1750.32	633.74

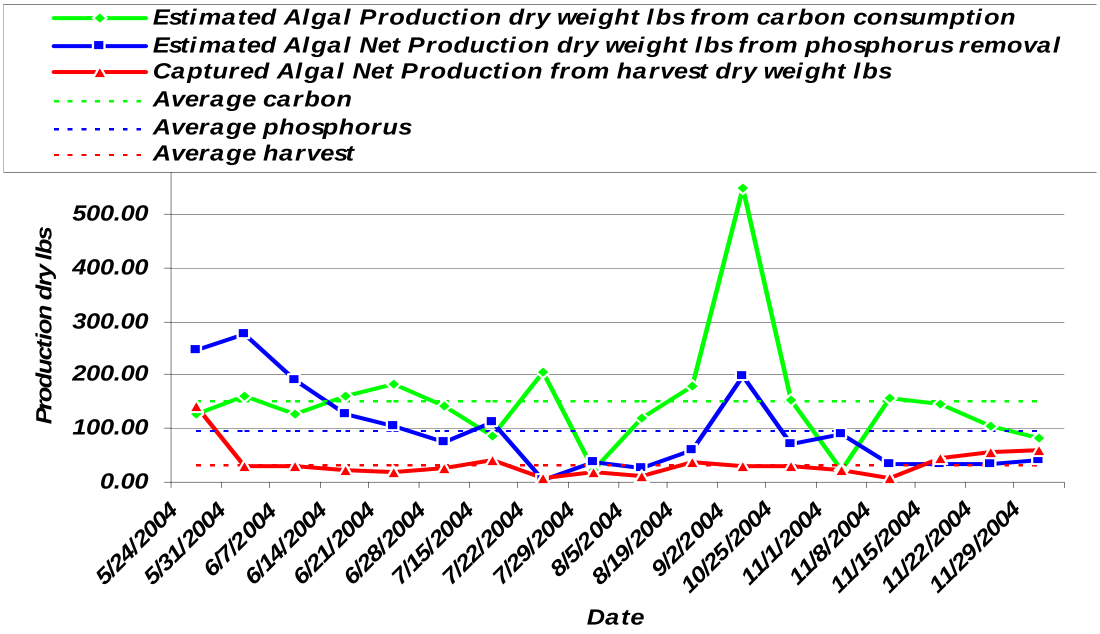


Figure 3-5: Trends in Carbon consumption based algal production estimates compared to actual harvest and phosphorus uptake based production projections Central single-stage ATS™ floway

Table 3-11: Carbon consumption based algal production estimates compared to actual harvest data and phosphorus uptake based production projections North single-stage ATS™ floway

Date	Alkalinity	Influent pH	Effluent pH*	Phosphorus Removed lbs	Algae Tissue Phosphorus content %dw	Influent Available Carbon Estimated mg/l	Effluent Available Carbon Estimated mg/l	Period Flow Gallons	Photoperiod % of diurnal cycle	Estimated Consumed Carbon lbs	Estimated Algal Production dry weight lbs from carbon consumption	Estimated Algal Production dry weight lbs from phosphorus removal	Captured Algal Production from harvest dry weight lbs
5/24/2004	36	6.75	8.10	0.58	0.60%	13.86	9.45	994,395	56.69%	20.71	60.92	96.20	57.19
5/31/2004	33	6.34	7.95	0.66	0.60%	19.14	8.84	482,069	56.69%	23.47	69.02	110.56	18.86
6/7/2004	26	6.33	7.77	0.33	0.60%	15.24	7.11	471,653	57.42%	18.35	53.97	55.73	28.00
6/14/2004	34	6.43	7.64	0.34	0.60%	17.98	9.45	458,640	57.42%	18.73	55.09	57.38	21.31
6/21/2004	32	6.34	8.33	0.30	0.60%	18.56	8.17	474,264	57.42%	23.61	69.46	50.10	11.40
6/28/2004	33	6.50	8.76	0.20	0.60%	16.23	7.95	442,512	57.42%	17.54	51.60	33.83	33.72
7/15/2004	36	6.90	9.18	0.31	0.42%	11.90	8.18	1,061,584	56.79%	18.70	55.01	74.68	42.48
7/22/2004	42	6.28	9.31	0.06	0.42%	25.74	9.36	478,529	56.79%	37.13	109.19	15.32	31.50
7/29/2004	37	7.29	8.79	0.18	0.50%	10.71	8.88	445,475	56.79%	3.85	11.33	36.35	30.63
8/5/2004	39	6.45	8.69	0.34	0.50%	20.22	9.49	410,703	53.10%	19.51	57.38	69.00	37.84
8/19/2004	44	6.56	8.43	0.16	0.50%	20.43	11.09	475,691	53.10%	19.69	57.92	31.44	60.75
9/2/2004	68	6.29	7.77	0.88	1.06%	41.37	18.61	766,859	49.21%	71.63	210.66	82.79	25.98
10/25/2004	40	6.24	8.09	0.34	0.73%	25.58	10.53	402,480	47.21%	23.86	70.16	45.98	24.14
11/1/2004	40	7.17	8.49	0.33	0.73%	11.74	9.99	443,232	44.50%	2.87	8.43	45.57	13.42
11/8/2004	42	6.26	8.41	0.24	0.94%	26.33	10.60	364,124	44.50%	21.25	62.50	25.85	35.32
11/15/2004	44	6.34	8.88	0.30	0.94%	25.46	10.43	453,884	44.50%	25.32	74.48	32.22	35.13
11/22/2004	45	6.53	9.00	0.31	0.94%	21.53	10.49	459,207	44.50%	18.82	55.35	32.59	31.02
11/29/2004	35	6.51	9.04	0.27	0.94%	17.09	8.11	465,499	44.50%	15.51	45.62	28.91	35.32
										Total	1178.12	924.49	574.01

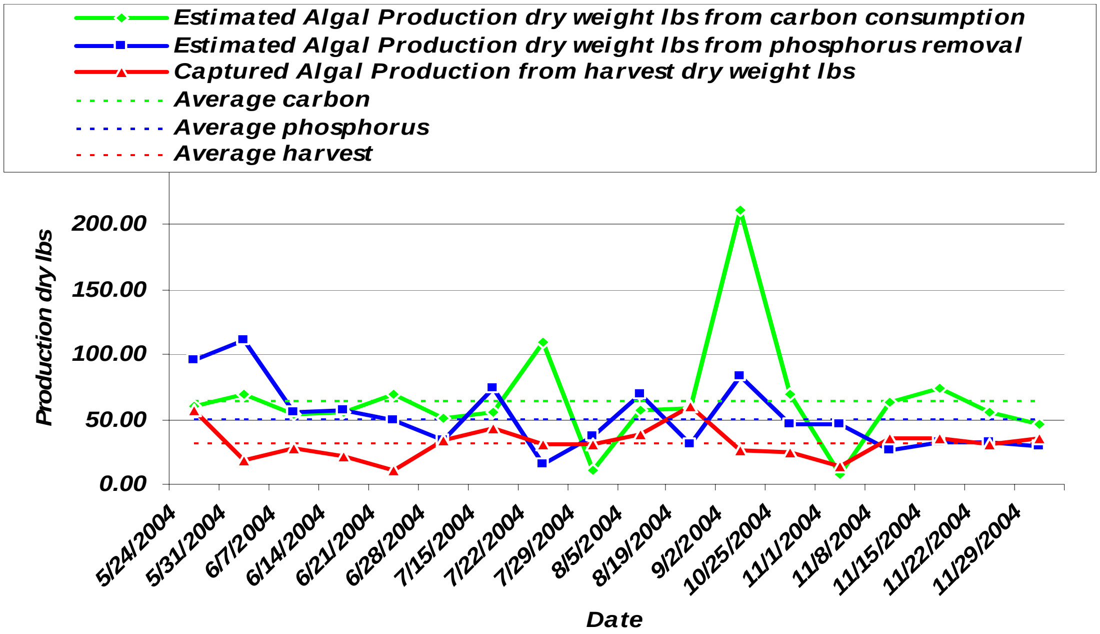


Figure 3-6: Trends in carbon consumption based algal production estimates compared to actual harvest and phosphorus uptake based production projections Central single-stage ATS™ floway

WATER & TISSUE PHOSPHORUS RELATIONSHIP

As with algae associated with other ATS™ systems, there is a discernible direct relationship between tissue phosphorus content and total phosphorus concentrations within the water column. As noted in Figure 3-7 there is a reasonable correlation associated with this relationship, and the slope is relatively steep. This same relationship is not seen with nitrogen, as noted in Figure 3-8, with a poor correlation coefficient and a rather flat slope. The general quality of the algae tissue from the single-stage floways is noted in Table 3-12.

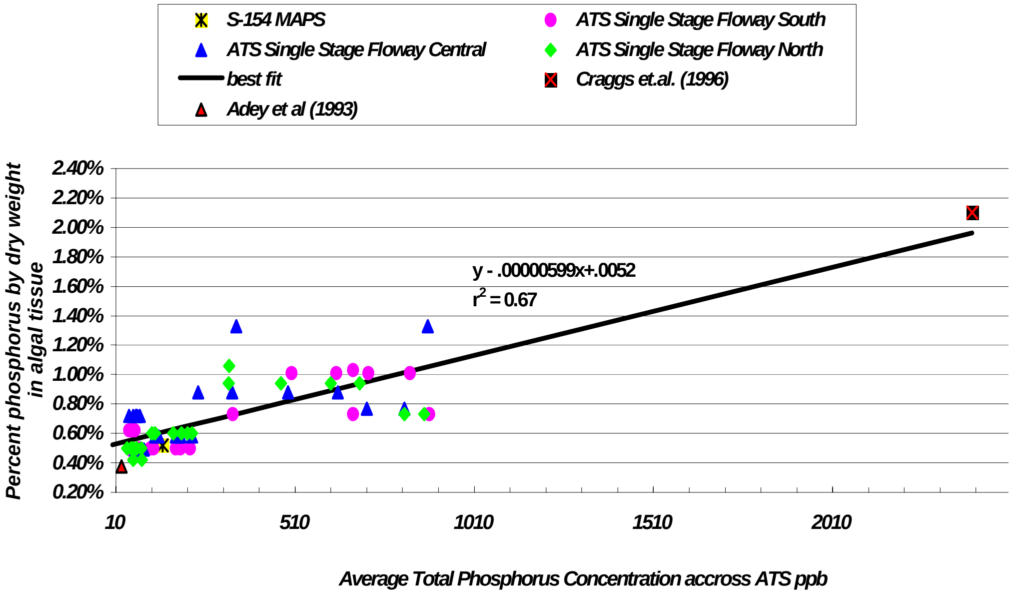


Figure 3-7: Relationship between phosphorus concentration and algae tissue phosphorus content

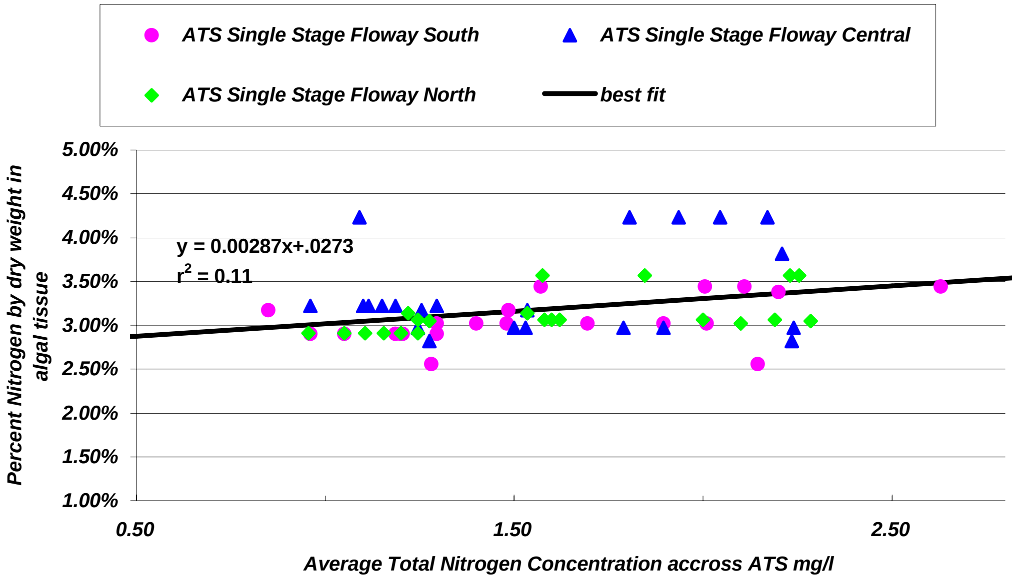


Figure 3-8: Relationship between nitrogen concentration and algae tissue nitrogen content

Table 3-12: Algae tissue quality single-stage ATS™ floways

	ATS South	ATS South	ATS South	ATS South	ATS Central	ATS Central	ATS Central	ATS Central	ATS North	ATS North	ATS North	ATS North
	Jun-04	Jul-04	Aug-04	Sep-04	Jun-04	Jul-04	Aug-04	Sep-04	Jun-04	Jul-04	Aug-04	Sep-04
Nitrogen % dw	3.02	3.17	2.90	3.38	2.97	3.17	3.22	3.82	3.06	3.14	2.91	3.23
Phosphorus % dw	0.50	0.48	0.62	1.03	0.58	0.49	0.72	1.33	0.60	0.42	0.58	1.06
Calcium % dw	0.62	1.74	2.33	2.35	2.12	1.41	2.73	2.05	2.34	1.73	1.79	2.19
Magnesium % dw	0.26	0.48	0.55	0.40	0.29	0.42	0.44	0.34	0.65	0.45	0.50	0.61
Sodium % dw	1.89	1.36	0.44	0.11	0.29	0.33	0.55	0.13	0.30	0.26	0.47	0.12
Potassium % dw	1.19	1.00	1.14	0.70	2.81	1.19	2.25	1.33	1.37	1.16	1.22	0.89
Sulfur % dw	1.19	1.00	1.04	0.65	1.31	1.02	1.37	0.76	1.37	0.90	1.02	0.63
Iron ppm dw	61,563	65,377	68,371	49,239	60,455	64,415	52,624	44,909	57,641	59,717	66,239	40,326
Manganese ppm dw	2,614	2,729	2,937	4,234	3,503	2,578	3,083	6,404	3,337	2,243	2,203	4,569
Copper ppm dw	18	20	17	23	16	18	17	15	25	14	25	14
Zinc ppm dw	109	104	139	181	102	80	139	174	132	78	128	146
Crude Protein % dw	18.90	19.80	20.50	21.10	18.40	19.80	22.50	23.90	19.10	19.60	20.80	20.20
Ash % dw	49.30	44.10	43.00	46.30	47.00	42.50	40.60	45.90	47.60	43.20	45.30	51.30

	ATS South	ATS South*	ATS Central	ATS Central*	ATS North	ATS Central*
	Oct-04	Nov-04	Oct-04	Nov-04	Oct-04	Nov-04
Nitrogen % dw	3.38	3.45	3.82	4.23	3.49	3.17
Phosphorus % dw	1.03	1.01	1.33	0.88	0.94	0.94
Calcium % dw	2.35	1.59	2.05	1.59	1.62	1.59
Magnesium % dw	0.40	0.40	0.34	0.40	0.42	0.40
Sodium % dw	0.11	0.14	0.12	0.14	0.11	0.14
Potassium % dw	0.70	3.63	0.89	3.63	0.78	3.63
Sulfur % dw	0.65	1.49	0.76	1.49	0.73	1.49
Iron ppm dw	49,239	20,178	44,909	20,178	34,148	20,178
Manganese ppm dw	4,234	3,247	6,404	3,247	4,080	3,247
Copper ppm dw	23	13	15	13	36	13
Zinc ppm dw	181	80	174	80	107	80
Crude Protein % dw	21.10	26.50	23.90	26.50	21.80	26.50
Ash % dw	46.30	36.70	45.90	36.70	48.70	36.70

*** All values in November except for N and P from a sample taken from the Main ATS.**

The levels of nitrogen, phosphorus, calcium, magnesium, copper, sulfur and zinc appear at levels sufficient to ensure they are not limiting growth. The potassium levels in the tissue are comparatively low, being below what has been reported as sufficiency levels of 2.0-3.0 % dw. It should be noted however that these sufficiency levels are based on research with terrestrial macrophytes and periphytic algae sufficiency levels may be different. Potassium concentrations within the water column of L-62 however, have typically been well above these projected sufficiency levels. During the entire POR associated with the single-stage ATS™ floways, there has been no nutrient supplementation.

Phosphorus tissue content is rather high, well above the sufficiency levels, as are iron and manganese. These elevated levels likely result from precipitation of phosphorus. In addition, luxury uptake of phosphorus, iron and manganese may be occurring.

SECTION 4. ASSESSMENT OF PERFORMANCE

PERFORMANCE ANALYSIS

When the nutrient loading rates from the single–stage ATS™ floway data for the entire adjusted POR, are applied as the independent (x) variable, and the nutrient removal rates are applied as the dependent variable (y) as noted within the scattergrams shown as Figures 4-1 and 4-2, it is noted that the data set from May through August are well correlated, with another set of reasonably correlated data from October to December. These trends are not as evident for nitrogen. These data provide support to the following implications:

1. Because of the high correlation between the two loading variables, even though there is some degree of autocorrelation, it is reasonable to assess the rate of phosphorus removal to be a function of phosphorus concentration, this being an indication of a first order reaction, as described by Michaelis-Menten for single substrate enzymatic reactions, or Monod in assessing growth responses to a limiting nutrient (Michaelis-Menten, 1913; Monod,1942).
2. There is indication that the linear hydraulic loading rate (LHLR) enhances nutrient removal rate, based upon the positioning of the data scatter for each of the three single-stage floways.
3. There is a higher correlation related to phosphorus than with nitrogen.
4. There are clearly lower rates in the October to December period, which are expected due to lower temperatures and shorter photoperiods, but may also be related to some extent to variations in nutrient availability and concentrations.

When influent concentration is set as the x-axis, the influence of autocorrelation is reduced, as the flow and area components are eliminated from the independent variable. As noted in Figure 4-3, there is reasonable correlation between influent phosphorus concentration and areal phosphorus removal rates during May through August. This correlation is not as close for the period October to December. The Central Floway with the higher LHLR show the greatest slope associated with the best-fit line for both periods, with the South Floway, with the lowest LHLR showing the lowest slopes, with the slope being negative during the period October to December, as seen in Figure 4-4.

The influence of the LHLR can be seen also in Figures 4-5 and 4-6. While it is understandable that the lower LHLR floways would be restricted to the area closer to the x-y intersection, as removal rate is limited by loading rate, the fact that there is a positive slope as LHLR increases indicates a positive relationship between LHLR and removal rates, and accordingly, one would expect, to growth rates. As all other variables were essentially the same in all three floways, it is reasonable to suspect that LHLR, a parameter related directly to flow velocity, is important to system performance.

The next section includes further assessment of concentrations and flow velocities upon rates. This includes a review of growth dynamics as related to Monod kinetics, and diffusion influences.

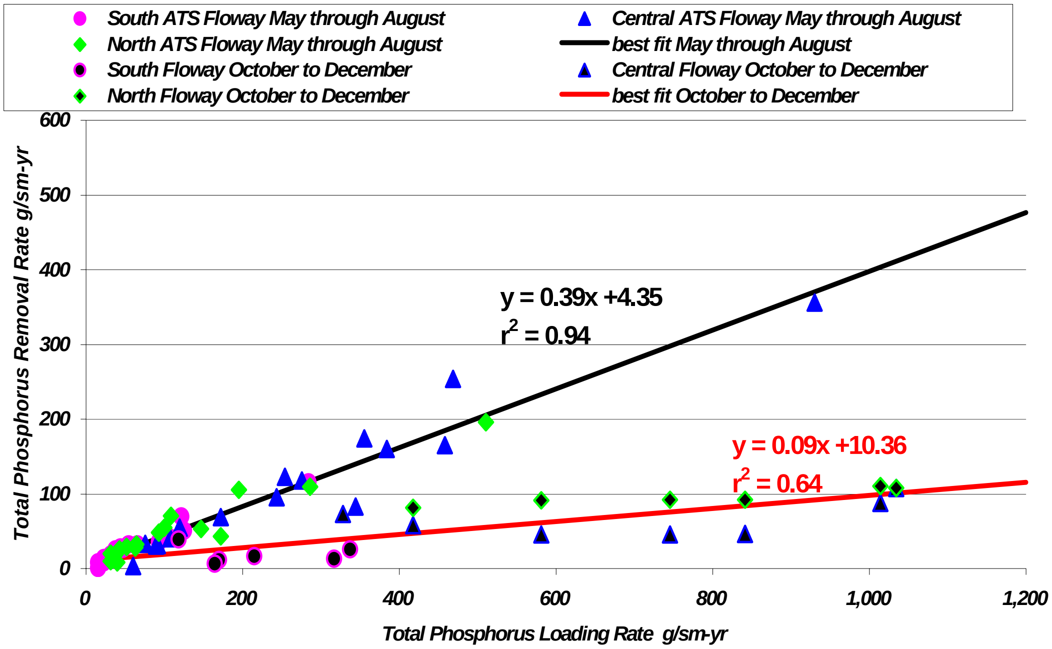


Figure 4-1: Areal removal rate trends for phosphorus during adjusted POR

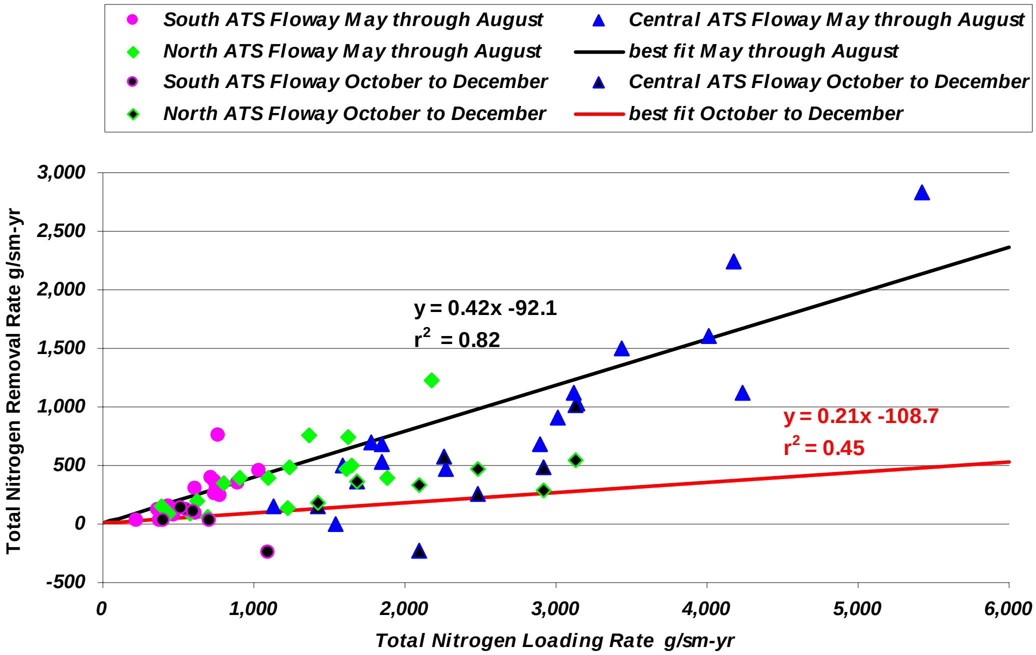


Figure 4-2: Areal removal rate trends for nitrogen during adjusted POR

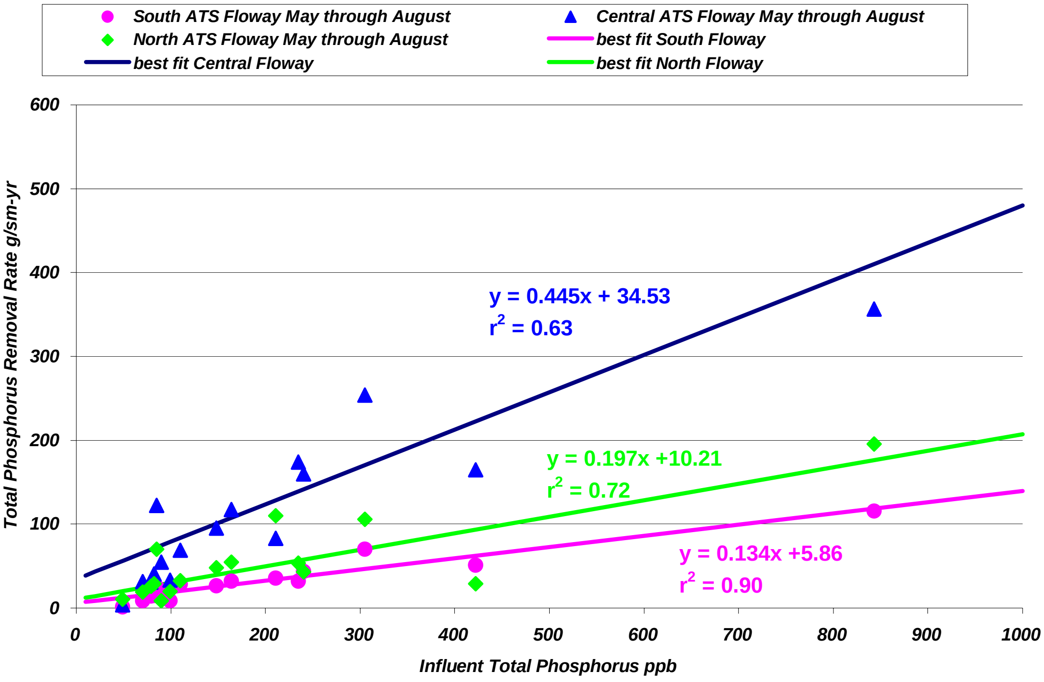


Figure 4-3: Phosphorus influent concentration versus phosphorus removal rate May through August 2004

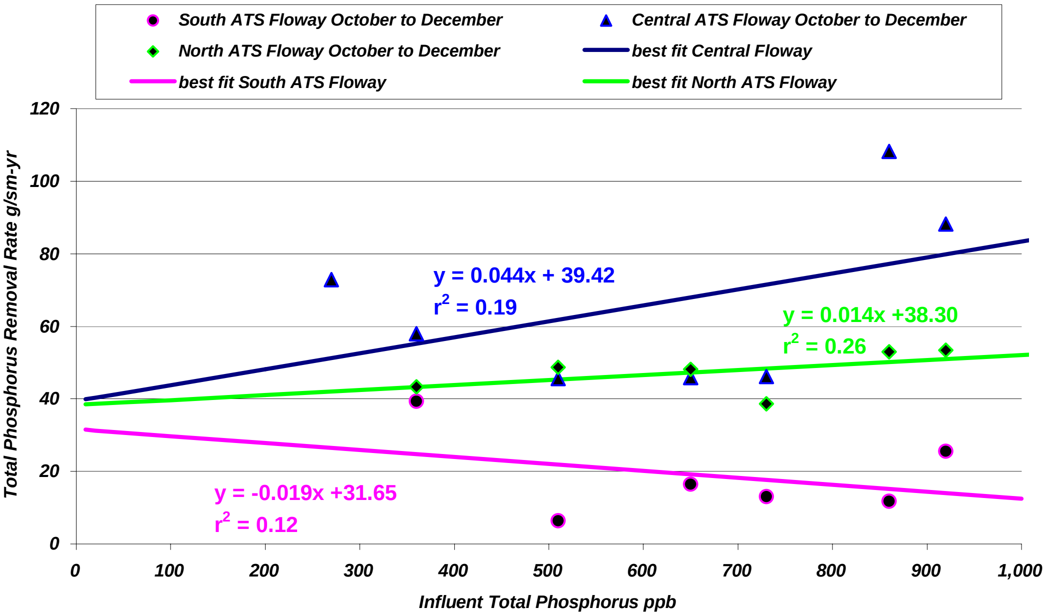


Figure 4-4: Phosphorus influent concentration versus phosphorus removal rate October to December 2004

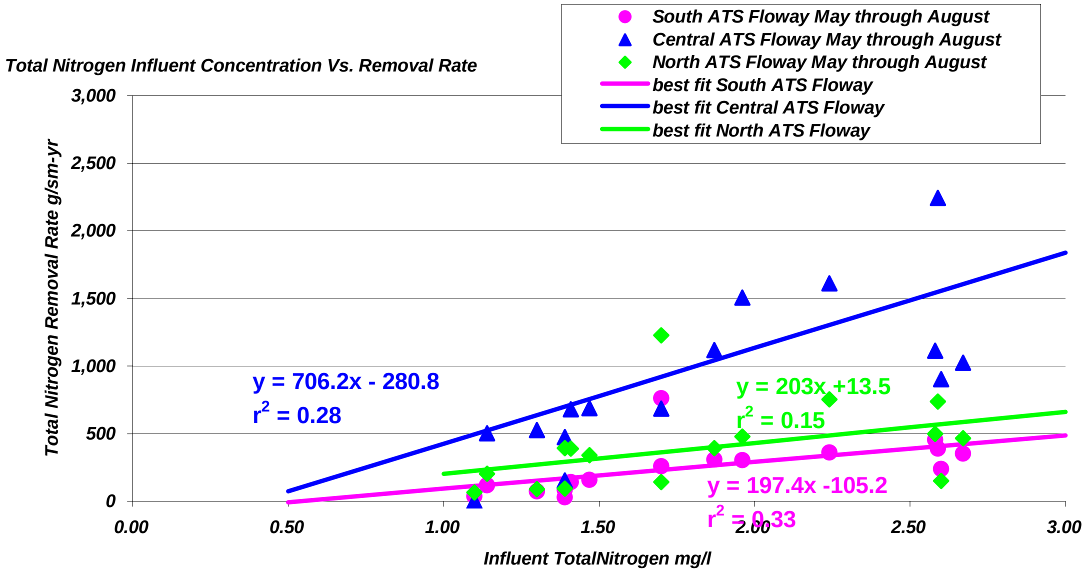


Figure 4-5: Nitrogen influent concentration versus nitrogen removal rate May through August 2004

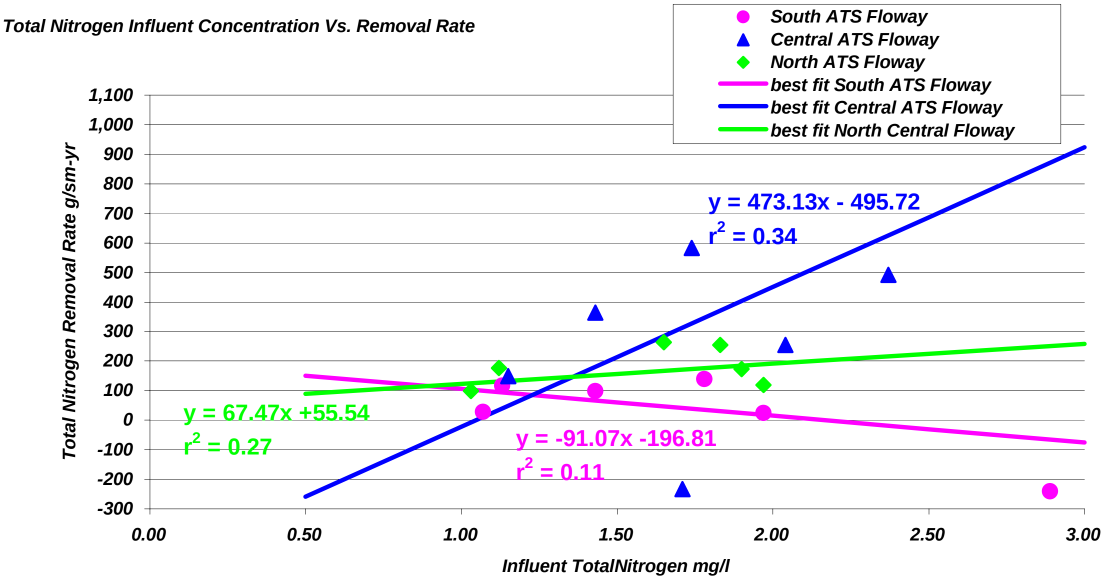


Figure 4-6: Nitrogen influent concentration versus nitrogen removal rate October to December 2004

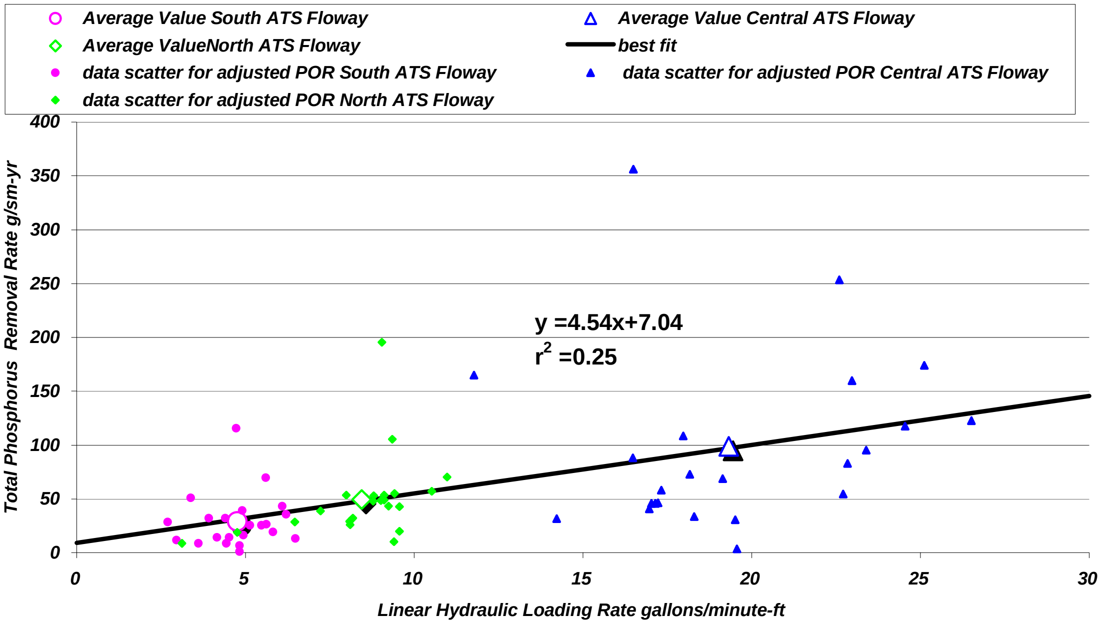


Figure 4-7: Comparison of LHLR and phosphorus removal rates over the adjusted POR single-stage floway

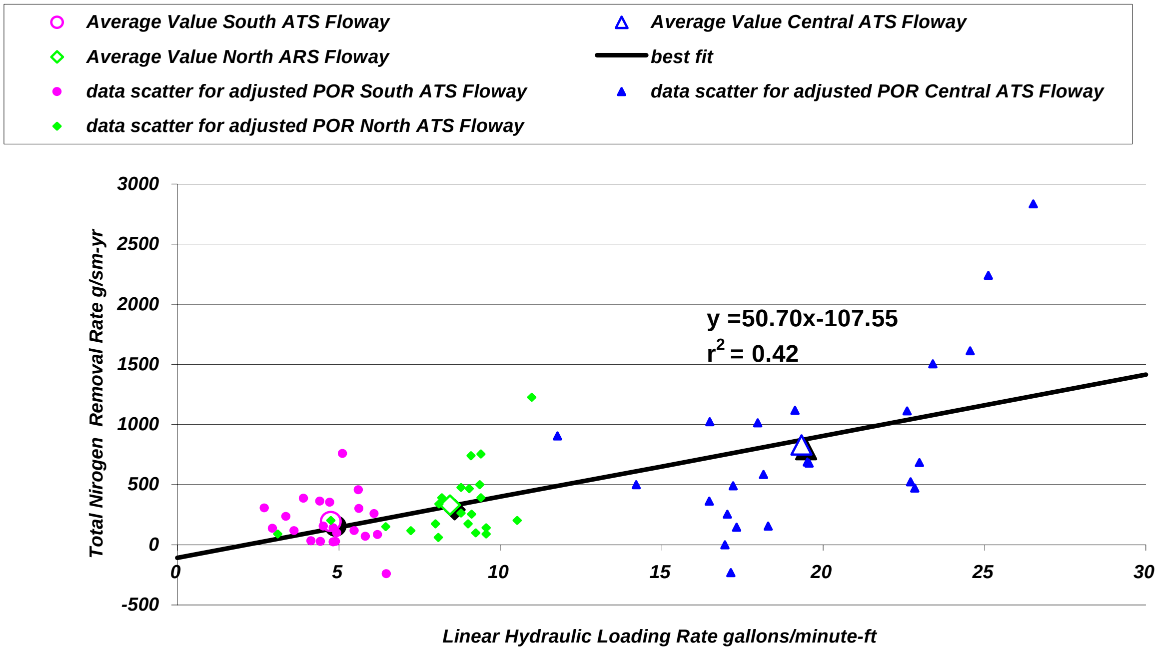


Figure 4-8: Comparison of LHLR and nitrogen removal rates over the adjusted POR single-stage

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, in modeling treatment wetlands, known as Stormwater Treatment Areas or STA, the resultant, documented removal of phosphorus was utilized to establish a general first order equation in which removal is projected, but the mechanisms involved are not individually assessed (Walker, 1995). 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 –"*The model makes no attempt to represent specific mechanisms, only their net consequences, as reflected by long-term average phosphorus budget of a given wetland segment."*

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

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.

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

or

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

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

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

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

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

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

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

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

$$Z_t = Z_0e^{\mu t} \qquad \textbf{Equation 4}$$

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

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

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

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

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

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

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

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

Where μ_{opt} is the growth rate for given **S** at the optimal growing temperature ^oC, $\mathbf{T}_{opt}$, and μ_1 is the growth rate for the same given **S** at some temperature ^oC, $\mathbf{T_1}$, when $\mathbf{T_1 < T}_{opt}$, and Q is an empirical constant ranging from 1.03 to 1.10.

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

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 Θ.

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

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

Estimation of μ_{max} and $\mathbf{K_s}$ can be done by manipulation of the Monod relationship, noted as Equation 5 to yield linear equations to which field data can be applied and plotted, as discussed by Brezonik (Monod, 1942; Brezonik, 1994). Several techniques are discussed, including Lineweaver-Burke, Hanes and Eadie-Hofstee. It is suggested that of the three methods, the Hanes method, which involves the plot of substrate concentrations **S**, as the independent variable, and the quotient of substrate concentration and growth rate, $[\mathbf{S}]/\mu$, as the dependent variable is the preferred of the three. In such a plot, μ_{max} is represented as the inverse of the slope of the linear equation:

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

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

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

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

1. Data was used for that period identified as the adjusted POR, as inclusion of results impacted

by the hurricane events, and the associated power outages represent unusual perturbations that would likely influence system performance. This POR was from May 17, 2004 to August 23, and October 23 to December 6, 2004.

2. Water loss was considered negligible down the ATS™.
3. Crop production was calculated as the mass of total phosphorus removed over the monitoring period divided by the tissue phosphorus content as % dry weight, with the tissue phosphorus content calculated using the equation note in Figure 3-7.
4. Growth rate is calculated by $\mathbf{ln(Z_t/Z_0)\ /t} = \mu$ 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 Θ**=** 1.10.
6. Substrate concentration is set as the mean between influent and effluent concentrations.
7. Available carbon concentration is calculated using the method described in Section 3-4.

Scattergrams of the total phosphorus, total nitrogen, available carbon, and linear hydraulic loading rate with calculated growth rate are noted in Figures 4-9 to 4-12. The patterns as seen provide indication that phosphorus influences upon growth rate are more dramatic at lower concentrations, with a “plateau” noted at high concentration indicating rather low values of $\mathbf{K_s}$**.** 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 includes in his discussions related to Monod and diffusion algal growth dynamics the recognition that more than one controlling factor may be involved, and that the Monod relationship may need to reflect this within the model, as noted in the following equation form:

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

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

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

Table 4-1: Data set for adjusted POR

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

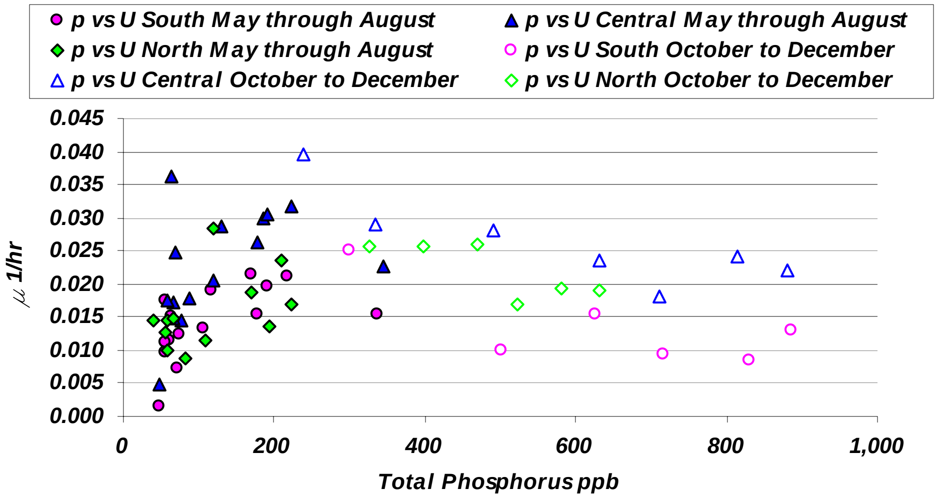


Figure 4-9: Total phosphorus Vs. calculated growth rate adjusted POR data set

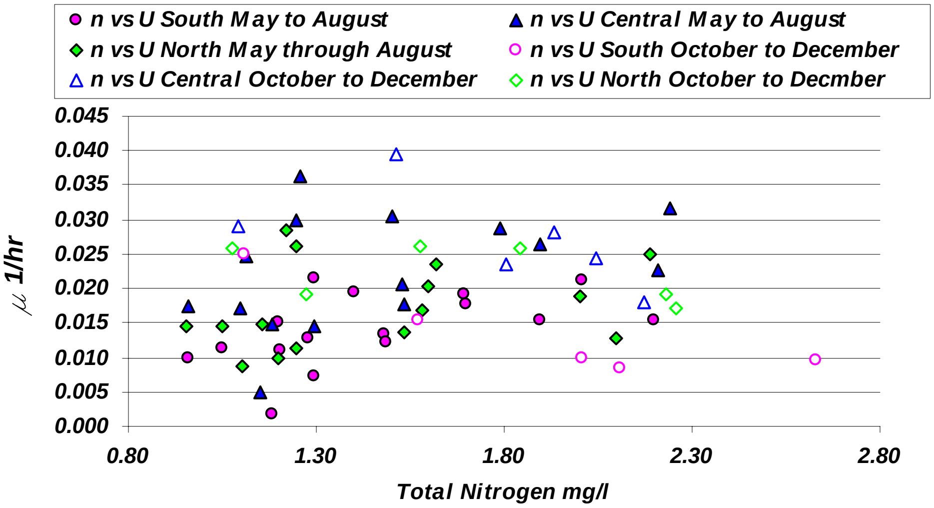


Figure 4-10: Total nitrogen Vs. calculated growth rate adjusted POR data set

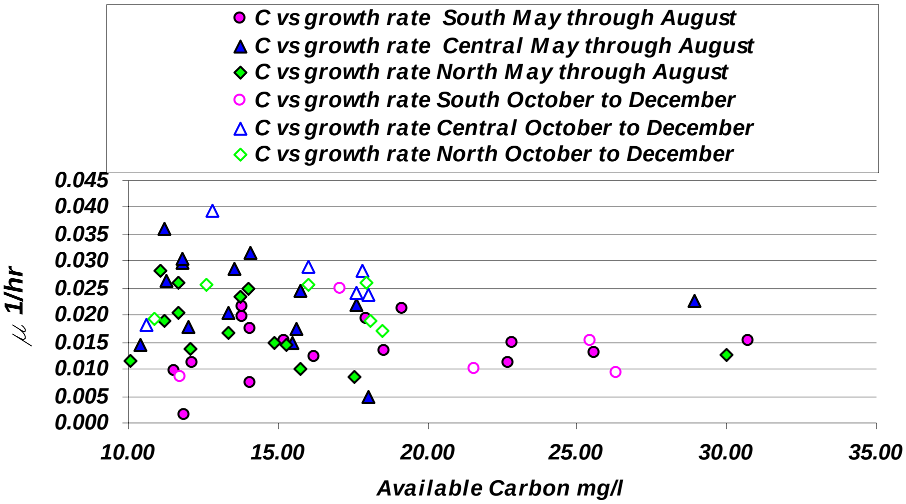


Figure 4-11: Available Carbon Vs. calculated growth rate adjusted POR data set

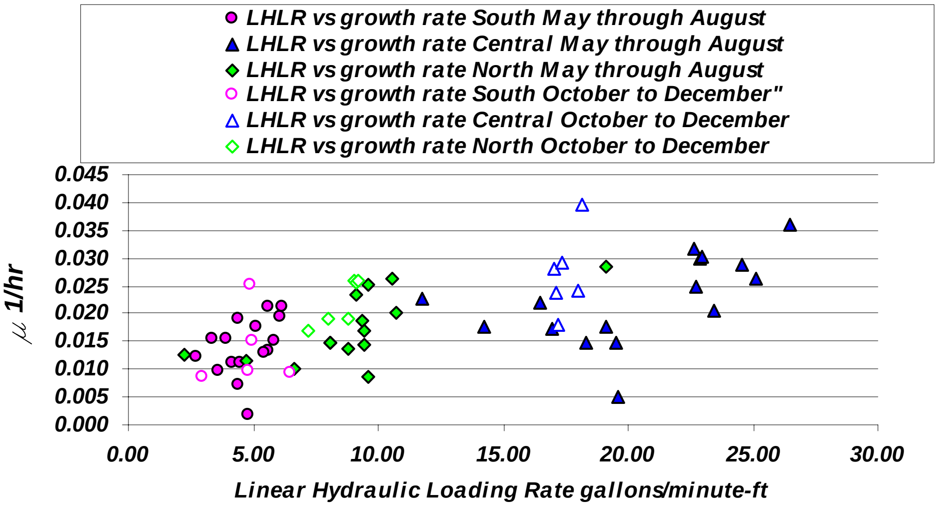


Figure 4-12: Linear Hydraulic Loading Rate Vs. calculated growth rate adjusted POR data set

Table 4-2: Results of Hanes analysis

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

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

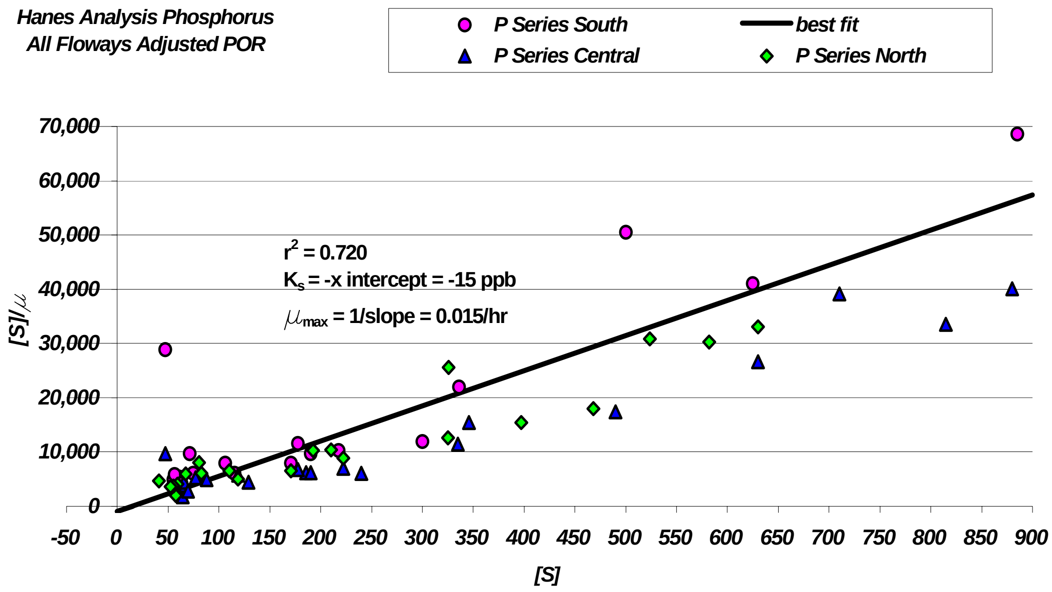


Figure 4-13: Hanes plot total phosphorus all floways over adjusted POR

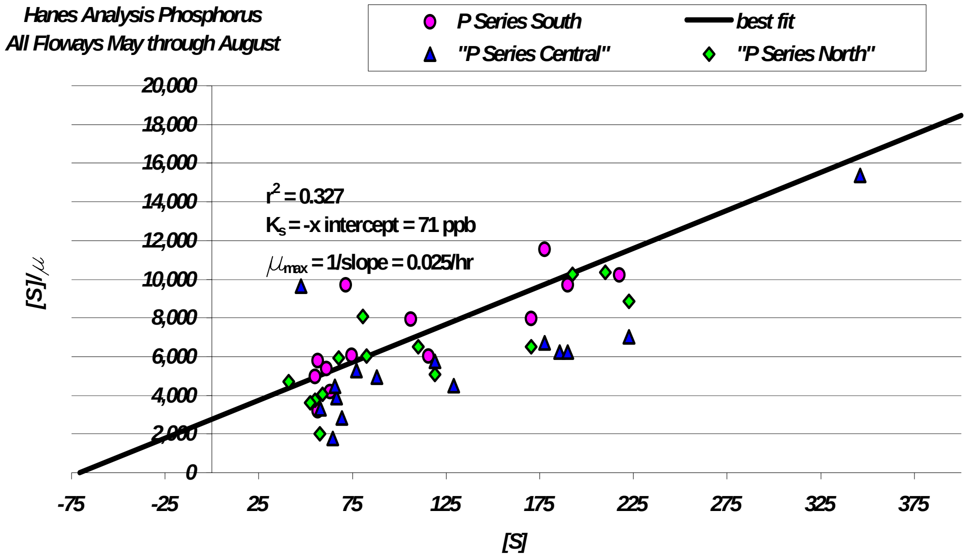


Figure 4-14: Hanes plot total phosphorus all floways May through August

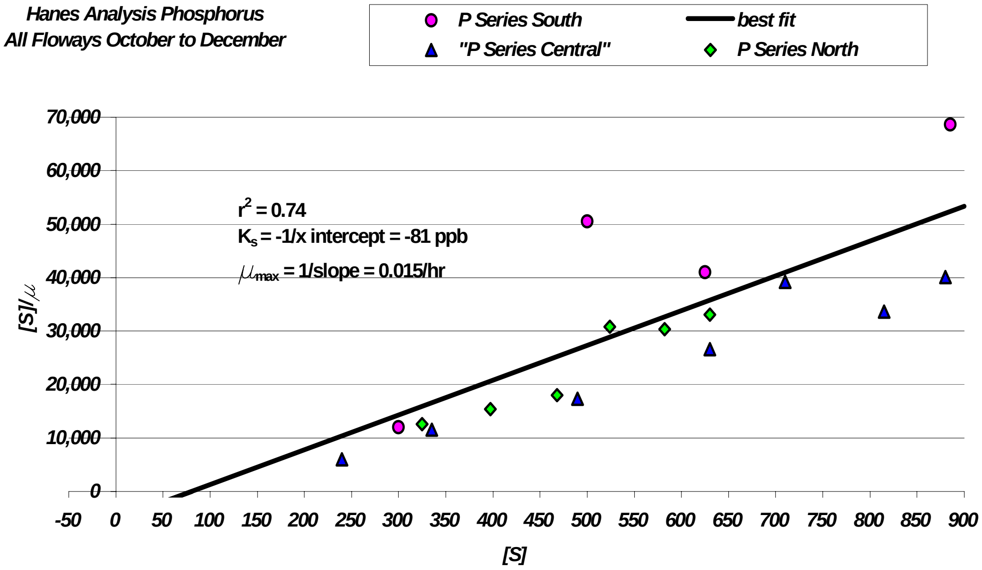


Figure 4-15: Hanes plot total phosphorus all floways October to December

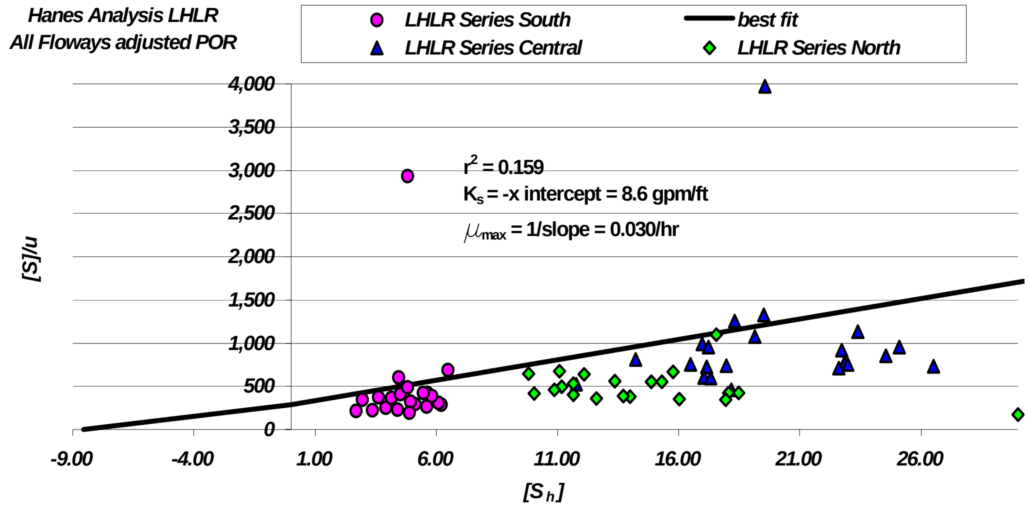


Figure 4-16: Hanes plot LHLR all floways over adjusted POR

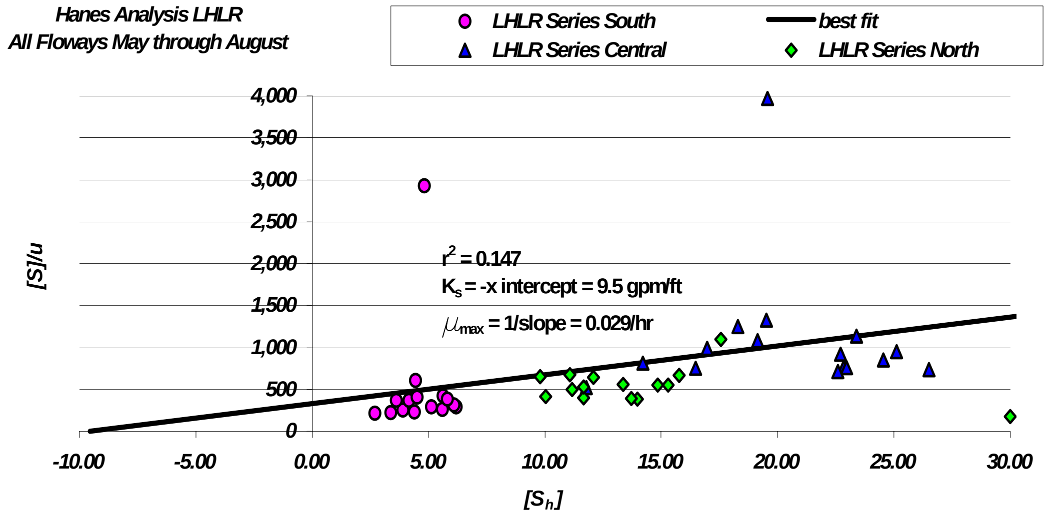


Figure 4-17: Hanes plot LHLR all floways May through August

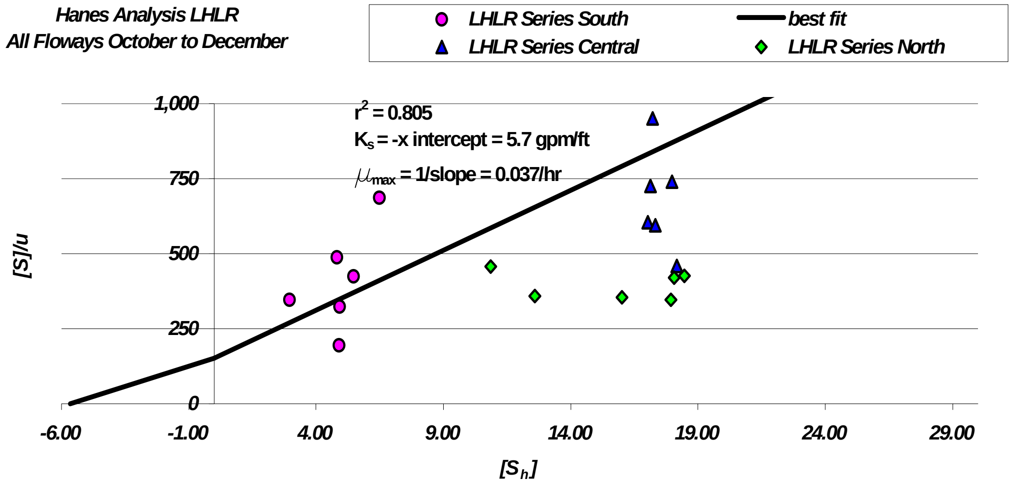


Figure 4-18: Hanes plot LHLR all floways October to December

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

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

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

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

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

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

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., 1991). 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 is inversely related to the gradient through which diffusion occurs (Carpenter et al., 1991; Brezonik, 1994). 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. In low nutrient conditions there exists a minimum velocity (u_{min}) at which diffusion limitation of nutrient uptake is avoided. This is defined mathematically as:

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

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

It is noteworthy that at low nutrient concentrations, adapted algae species would likely be characterized by a low K_s value. This is validated by Brezonik, who notes the difficulty in determining the controlling influence of nutrients upon algae production at low nutrient levels, as "*K_s may be below analytical detection limits—making it difficult to define the μ vs. [S] curve*." He includes some of the documented K_s values for several algae species associated with low nutrients. Phosphate appears as a limiting nutrient in several cases, with K_s values as low as 0.03 μM as PO_4, or about 3 ppb as PO_4, or just less than 1 ppb as phosphorus. As K_s is directly proportional to P', then it would not be unexpected that at low nutrient levels, P' would be comparatively small, and hence u_{min} comparatively large—the implication being that elimination of diffusion influence becomes very important, and hence flow velocity becomes an important design parameter. As noted, Kadlec and Walker 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, in which two factors are included in the Monod equation (see Equation 10). It is then reasonable to include both total phosphorus and LHLR in the case of this dataset. The parameters $\mathbf{K_s}$ and μ_{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:

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

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

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

Z_o = Initial algal standing crop at beginning of sampling period

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

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

L_p = Linear Hydraulic Loading Rate for sampling period

K_{hp} = Monod half-rate coefficient LHLR

t = sampling period time in days

V_p = Volume of flow during sampling period

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

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

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

Central

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

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

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

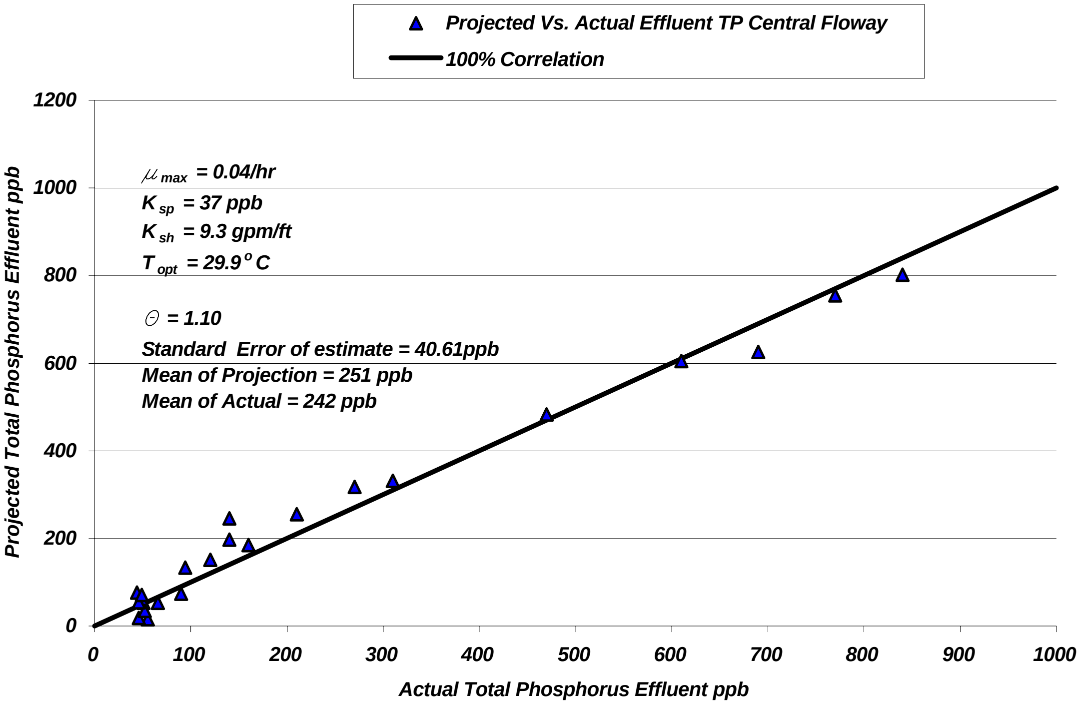


Figure 4-19: Actual Vs. ATSDEM Projected total phosphorus effluent concentration Central Floway

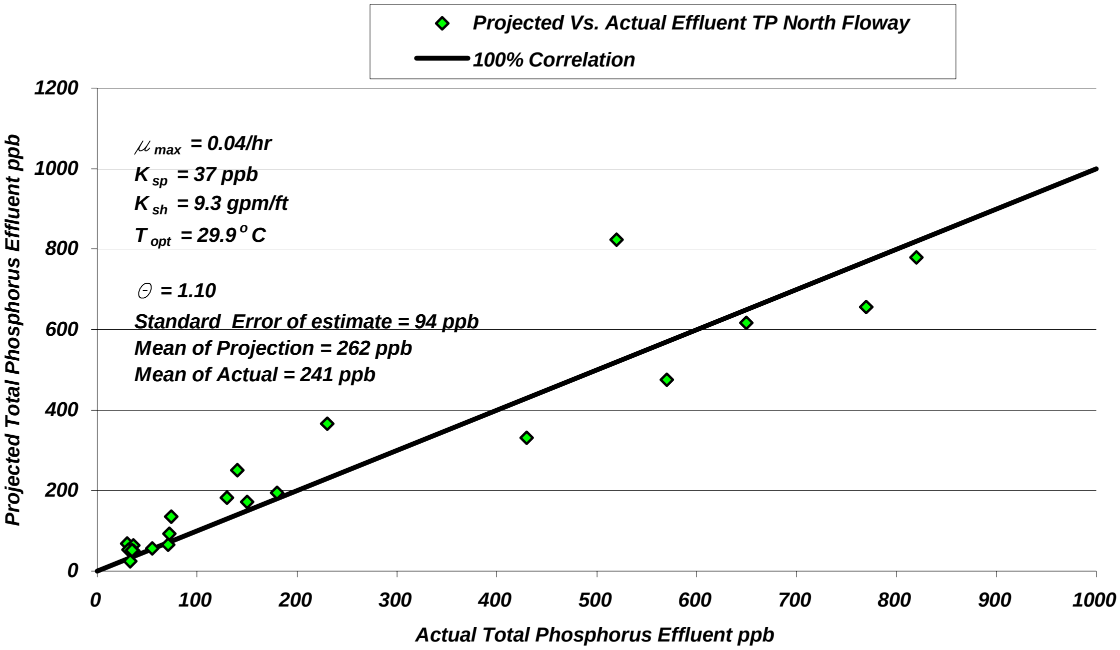


Figure 4-20: Actual Vs. ATSDEM Projected total phosphorus effluent concentration North Floway

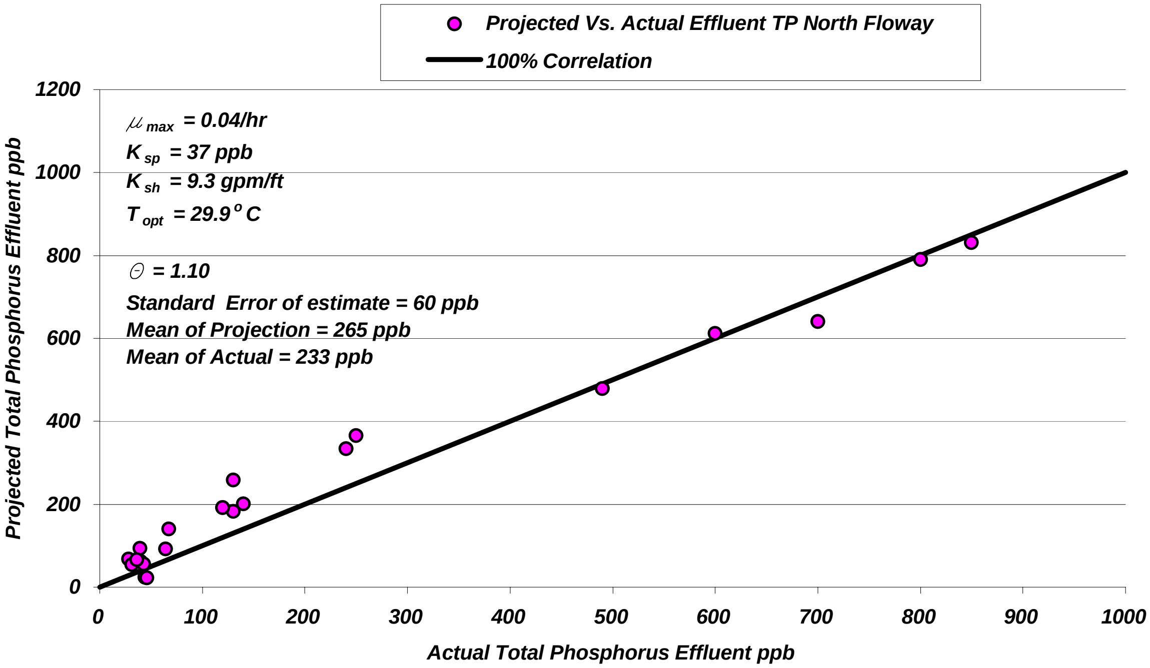


Figure 4-21: Actual Vs. ATSDEM Projected total phosphorus effluent concentration South Floway

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

A Practical EXCEL Spreadsheet based ATSDEM

While very complex computer models could certainly be developed for sizing and designing ATS™ systems, a practical 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 successional pressures. This general strategy is the foundation of all MAPS technologies, as well as heterotrophic based systems, such as activated sludge.

It is typical that the harvesting frequency for an ATS™ in warm season conditions will be about every seven days, meaning that the entire ATS™ floway is completely harvested every seven days. In the cooler season, this frequency will typically increase to about a 14 day cycle. ATSDEM projections are based upon a composite average 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.

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

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 an average, the model effluent estimate and actual composite effluent can be expected to be similar. This applies to any time period during the operation. While photosynthesis occurs only during the daytime, productivity projections are based upon a 24-hour period, as experience indicates that nutrient uptake continues 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 4-21.

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

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

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

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

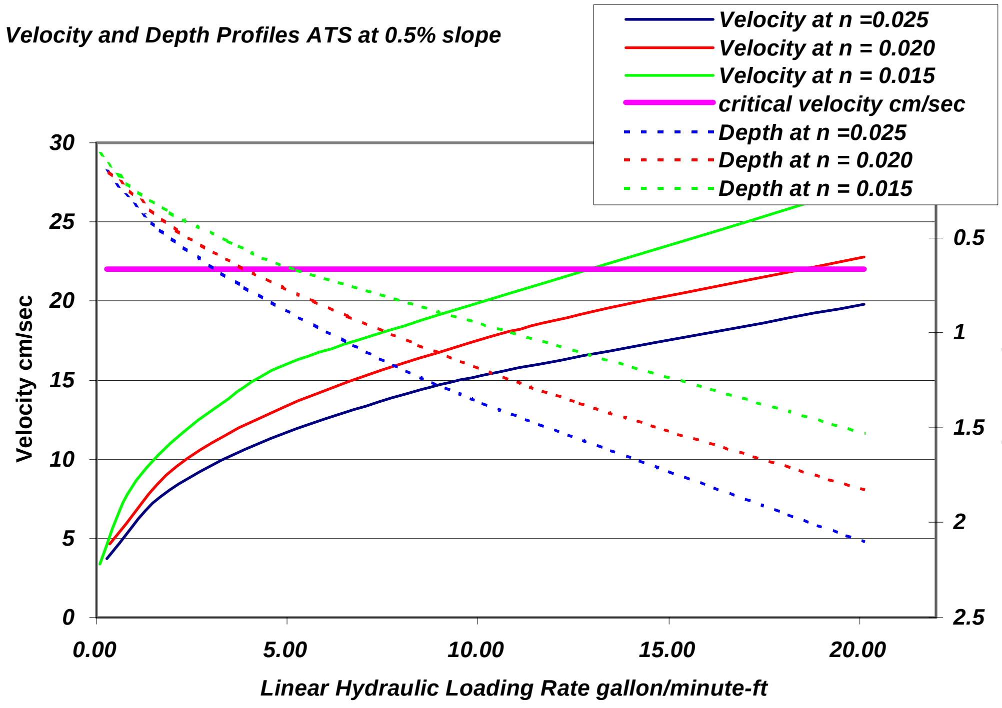
The change in floway length traversed by the control volume, with time, **dL/dt**, is expressed as:

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

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

The actual format for the ATSDEM spreadsheet model includes a front-end tutorial sheet, followed by a Design Parameter and Summary Worksheet, followed by a Z_{AVE} worksheet, and finally the Model Run Worksheet. These are presented within Appendix A.

The example used for the model run is for a proposed 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 ppb, and evaluating the proposed facility over four quarters, using water temperature from existing field data, the annual total phosphorus removal, as noted in Table 4-4, 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 4-22.



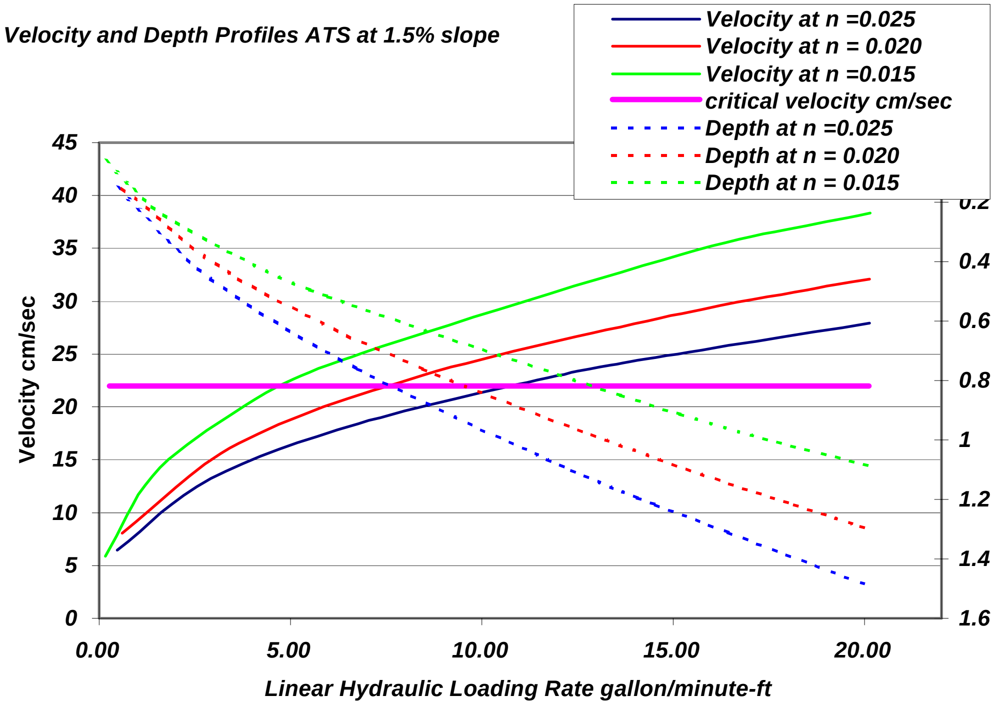


Figure 4-21: Velocity, LHLR and depth relationships as determined from Manning Equation

Table 4-4: 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	Θ	K_{sp} as ppb TP	K_{sh} as LHLR gpm/ft	μmax 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	μ_{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 4-22: Conceptual Design Parameter and Summary Worksheet Lake Okeechobee Watershed Quarter 2 ATS™ 25 MGD

ASSESSMENT OF HURRICANE IMPACTS

As mentioned previously, Hurricane Frances passed over the S-154 site on September 3 and 4, 2004. Based upon review of weather data, it appears that wind velocities approached 95 mph for a sustained period. Rainfall exceeded 7”—the limit of the on-site gauge—and may well have been close to 10”. Sometime during this period, power was lost, and the operations terminated. The runoff associated with the heavy rainfall, combined with wind, scoured the ATS™ units, resulting in a flushing of algae solids and nutrients. Sampling was terminated with the loss of power.

After Hurricane Frances, the facility was inspected, and no significant damage was recorded. However, power remained off until the late afternoon, September 14, 2004. At that time the system was returned to operation until September 27, 2004, when the facility was hit by Hurricane Jeanne, which had associated wind and rainfall similar to Frances. The power was again lost, and did not return until October 3, 2004. Therefore the system experienced 18 days of power outage in the one-month period between September 3, 2004 and October 3, 2004. Water quality and field data for the period following Hurricane Jeanne appeared to return too normal by October 23, 2004. .

Based upon data collected from the week of August 30, 2004 (which includes the hurricane related samples of September 3-4) to October 25, 2004, the system shows the ability to recover in a relatively short time period. This is also supported by the sustenance of performance during the numerous shut downs over the POR. The performance of the system following Hurricane Frances and Jeanne is noted in Figure 5-1. Following a release of nutrients during the week of the hurricane, there was some recovery after re-start on September 14, 2004. After Hurricane Jeanne, the system showed recovery by the week ending October 25, 2004.The indication is that algal growth recovery is rather rapid. After the two power outages, no effort was made to remove the necrotic algae from the floway prior to restart. If this had been done, it is possible that the rate and extent of recovery would have been improved. However, considering the magnitude of these events, it can be said with confidence that ATS™ system are resilient, and capable of returning to full performance in a short period after extensive dry-down. Therefore, it would not be unreasonable to consider, where appropriate, a system that would function over a portion of the year, while being retired for the remainder. This might work well where seasonal allocations apply, or where annual load removal requirements can be accomplished during the growing season.

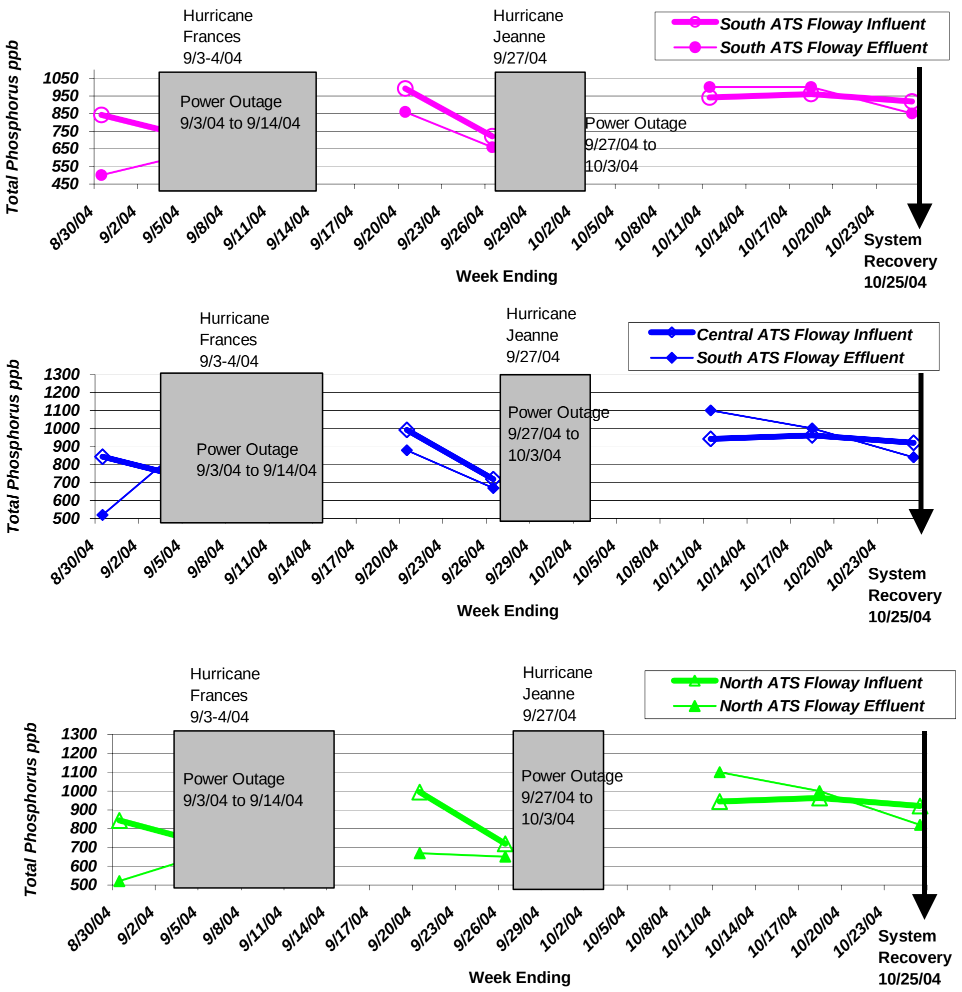


Figure 5-1: System phosphorus removal performance during impact period related to Hurricane Frances

SECTION 5. DISCUSSION

Response To Inquires

> *Question 1. Page iii. Be consistent with the use of abbreviations throughout the report. For example, milligrams per liter were abbreviated as "mg/l" on the list of abbreviations, and as mg/l in tables, figures and text.*

Reply: This item has been addressed within the text.

> *Question 2. Was the last day of operation for the Central Floway December 5 or 6, 2004? Text says December 5, tables and figures show December 6.*

Reply: The last operational day was December 5, 2004. The December 6th date is the default value given to the weekly scale in Microsoft Excel. This item has been addressed within the text.

> *Question 3. Treatment wetlands constructed and operated in the LOW may reasonably be expected to develop and perform differently from the Everglades STAs due to differences in soil properties, plant communities, surface water TP concentrations, rainfall patterns and hydraulic loads.*

Reply: The comparison between Everglades STA and Single-Stage ATS™ areal removal rates was made in an effort to relate actual ATS™ system performance to that of actual large-scale treatment wetland systems currently operated by SFWMD. Available performance data for treatment wetland systems in the LOW are limited to research scale mesocosm studies or model projections. Comparisons of Single-Stage ATS™ performance data to these two sources are provided below.

Available treatment wetland performance for the Lake Okeechobee Watershed is provided through a mesocosm study conducted on the S-154 site from March through October 2003. This University of Florida Institute of Food and Agricultural Sciences (UF-IFAS) sponsored study used the same source water as the HydroMentia ATS-WHS™ project. The mesocosm study included determination of treatment wetland nutrient removal capacity under various wetland/crop plant configurations. During this operational period influent TP concentration was 480 ppb, compared to mean influent TP concentration for the Single-Stage ATS™ of 333 ppb (May through December, 2004). Of the wetland systems investigated, highest areal removal rates were recorded for the water hyacinth mesocosm (42 g/m^2/yr with HLR of 58 cm/d), followed by periphyton mesocosm at 9.7 g/m^2/yr HLR 11 cm/d. Other configurations were investigated as well, including emergent wetland (cattail) followed by submerged aquatic vegetation (SAV), and water hyacinth followed by periphyton. These systems produced phosphorus areal removal rates of 3.7 g/m^2/yr and 11.7 g/m^2/yr, respectively (DB Labs, 2003). By comparison, at the lower phosphorus inflow concentrations, the HydroMentia Single-Stage ATS™ system removed 25, 47 and 92 g/m^2/yr at HLRs of 92, 157 and 368 cm/d, respectively. As phosphorus areal removal rates are projected to increase with increased phosphorus influent concentration, it follows that areal removal rates for the Single-Stage ATS™ would be greater when exposed to influent TP concentration of 480 ppb, further supporting findings illustrated in Table ES-1.

DMSTA model projections for two types of treatment wetland systems (1) submerged aquatic vegetation (SAV-STA) and (2) emergent wetland systems (EMA-STA) were reported in the LOW Project Water Quality Treatment Ranking (Central and Southern CERP Section X.X, 2003). Of the sites reviewed in this document, mean influent TP concentration at S-154 during the Single-Stage ATS™ study was closest to that used in developing the DMSTA model for Fish Eating Creek (Southwest of the S-154 Basin), therefore DMSTA design projections for that basin are presented for comparison in Table 1-1.

Table 1-1. Comparison of available treatment wetland model and mesocosm study results for the Lower Okeechobee Watershed with findings for the S-154 Single-Stage ATS™ study.

Site	Data Type	TP_{IN} (ppb)	TP_{OUT} (ppb)	Treatment Technology	HLR (cm/day)	TP Areal Loading Rate (g/m^2/yr)	TP Areal Removal Rate (g/m^2/yr)
Fish Eating Creek	Model	329	250	SAV- STA	3.3	4.0	0.95
				EMA-STA	1.2	1.4	0.34
S-154 Constructed Wetland Study (IFAS)	Actual	480	283	Water Hyacinth	58	102	42
			240	Periphyton	11	19.2	9.7
			209	Water Hyacinth followed by Periphyton	9	15.8	5.5
			169	Cattail followed by SAV	5	8.8	3.72
S-154 Single-Stage ATS™	Actual	336	250	South ATS™ Floway	92	109	25
			249	North ATS™ Floway	157	157	47
		333	258	Central ATS™ Floway	368	397	92

Question 4. There are missing values for in the ortho-P column for influent and effluent. Are they regarded as zero or no data? In the same column, effluent ortho-P values are higher than influent ortho-P from 11/8/04-11/22/04. The same is true for all nitrogen species on 11/8/04. What triggered the release of soluble P and N into the discharge water during these periods of operation? Also, why is effluent ortho-P higher than effluent TP on 11/22/04?

Reply: The missing values in the tables are regarded as "no data" and have been up-dated to reflect this within the text. Note that ortho-P is collected as a one-time weekly grab sample. The ratio of ortho to total phosphorus in the grab sample is applied in calculating reported ortho-P values, as in the main system reports. While calculated effluent concentrations were greater than influent concentrations for ortho-P for the period 11/15/04 to 11/29/04, and nitrate-N from 11/15/04 to 11/22/04, ortho-P was not greater than TP on 11/22/04 as this seems to be a typographical error. In this case, ortho-P was a greater percentage of total P upon effluent in the grab sample, which inflates the calculated value with respect to influent. However, raw data for these parameters shows increased nutrient concentrations, which are slightly outside of computational error range, indicating that there is an actual increase upon effluent. This is likely due to sloughing of algal material following desiccation during the hurricanes as the grid was not harvested prior to restarting flow. Note that few inferences of ATS™ performance with respect to ortho-P removal are made based on these data as they represent just a snapshot of ATS™ dynamics.

$$OP_7 = (OP_g / TP_g)\ TP_7 \qquad \textbf{(Equation 1)}$$

Where OP_7 = ortho P concentration for week
OP_g = ortho P concentration for grab sample
TP_g = total P concentration for grab sample
TP_7 = total P concentration for 7-day timed composite

Question 5. Page 16, Tables 2-5 and 2-6. Please see comment #4.

Reply: Please see Reply #4.

Question 6. Pages 23-25; 28-30 tables 2-9 to 2-14. Indicate the values in the last two rows of the tables as being sum or arithmetic mean of all observations as the case may be, with a footnote.

Reply: The value descriptions in the last two rows are arithmetic means for the period and have been modified to reflect this in the text.

Question 7. Page 33, 3rd paragraph. Inadequate sampling methods and analytical techniques are cited as a likely cause of observed variability in the amounts of recovered nutrients. What specific sampling and analytical protocols would you change to produce better results?

Reply: We can identify two possible reasons for variability in expected vs. measured biomass nutrient content. .

1) The analyzed harvest is a homogenized sample from the entire floway as described in the approved S-154 Monitoring and QAQC plan (September, 2004). There may be "hot-spots" of high or low phosphorus concentration where more phosphorus is assimilated but is not necessarily accounted for in the sample (i.e. the median phosphorus percent may be significantly greater than the mean in some places along the floway). Collecting samples at various transect points along the floway and applying that to measured algal mass for each transect may provide better accountability.
2) As discussed in the text (see excerpt below), a significant amount of detached algae has been observed within effluent water immediately following harvest. This harvest induced sloughing was investigated, as a one-time grab sample after harvest. Careful monitoring of this post-harvest water would also be expected to increase accountability. While potentially worthwhile, this level of analysis was beyond the scope of this study.

"Recognizing this, some effort was made during harvest of the single-stage floways to reduce "harvest induced sloughing" percentage by terminating flow during the short harvest period. Based on this protocol, following harvest, when the flow was returned, it was noted that some turbidity persisted within the effluent, for a brief period, typically less than 60 minutes. To quantify the characteristics of these harvest flows, a single grab sample of this turbid flow was taken from the Central Floway, and was analyzed for total phosphorus. It was found to contain 1.70 mg/l total phosphorus. Over a 60-minute period at 100 gpm, assuming this represents a mean concentration during the "harvest induced sloughing" period, about 0.09 lb/week of phosphorus, when harvested once weekly, would be lost through the Central Floway effluent, or a total of perhaps 1.98 pounds over the entire adjusted POR. This would represent about 43% of the phosphorus accounted for in the collected harvest associated with the Central Floway, or an additional 16% of the calculated removed phosphorus, which would increase phosphorus accountability to 53%."

Question 8. Page 33, last paragraph. What do you mean by "very limited storage space for accumulation of precipitates not associated with the recovered biomass"? Was there an attempt to quantify loss of P via precipitation/adsorption reactions?

Reply: Typical storage compartments in aquatic systems are; water-column, sediment and biomass. The mean depth on the ATS™ was 0.6 inches, with a hydraulic retention time of 11-20 minutes. This relatively small water volume coupled with high water turnover rate would generally indicate low nutrient storage capabilities in the water column. Therefore, phosphorus removed from the water is stored either as cellular biomass or as precipitate on the algal cells, which is removed through biomass recovery, leaving a nearly “blank slate” after each harvest event. Analytical methods to quantify precipitated phosphorus are costly and were beyond the scope of this study.

> *Question 9. Pages 34-35, tables 3-2 to 3-4. Percent nutrient recoveries greater than 100% indicate that there was more P in the harvested biomass than P removed per water quality. What were the likely sources of additional P associated with the biomass?*

Reply: It is possible that some of the algal mat remaining attached after hand harvesting was collected in subsequent harvests. It was originally thought that a small amount of “seed” algae should be left intact on the matrix to promote algal growth. During the single stage study, tissue analysis and growth rate indicated that adequate “seed” was available even with what appeared to be complete removal of the algal mass from the matrix with each harvest. Note that the percent recovery increased considerably after the week of 11/8/05, when this process was enacted.

According to the QAQC and Monitoring plans approved by the District, analysis of harvest plant nutrient and calculated budgets are provided as a third level of treatment performance indicators. More accurate and important performance measurements are determined through water quality analysis, and then internal vegetation and water quality analysis (See HMI S-154 Final Monitoring and QA/QC plan, Section 2.3). These data are presented only in order to better understand biomass nutrient removal, as well as to investigate harvest method efficiency for operational optimization. Information presented here is to be evaluated in this way and should not be used as a meaningful indicator of treatment system performance. It is acknowledged that certain error is associated with these calculations, and Tables 2-3 and 2-4 are provided as a comparison estimate only.

> *Question 10. Page 41, 4th paragraph, last sentence. Was the assumption about algal tissue being 33% carbon by weight based on literature values reported for similar algal communities?*

Reply: Microbial tissue is found to be 20-40% carbon, depending on the species. The value of 33% is consistent with that found in literature (Brezonik, 1994).

> *Question 11. Page 46, Fig. 3-8. Why was there no correlation found between algae tissue N content and total N concentrations within the water?*

Reply: While the variability in TN of influent water fluctuated considerably, and overall the majority of it was in recalcitrant, organic form. Note that TKN constitutes an average of 97% of TN concentration for the study period. More labile forms of nitrogen (NO_3-N and to a lesser extent NH_4-N) were generally below detectible limits or very low in influent water. There is not a strong correlation between increased influent TN concentration and increased influent NO_3 or NH_4 concentration ($R^2=0.004$ and $R^2=0.14$, respectively). Consequently, algae production and nitrogen uptake are likely more dependent upon the rate at which nitrogen is made available in these labile forms, rather than the concentration of total nitrogen.

> *Question 12. Page 46, Table 3-12. Were the high concentrations of iron and manganese in algal tissue as reflection of what was seen in L-62 water?*

Reply: As noted, there were sufficient levels of iron and manganese in influent water. It is possible that luxury uptake of these micronutrients occurs when they are available in excess, or the tissue content is elevated because of the intermingling of precipitated iron and manganese salts.

> *Question 13. Pages 49-53. Compared to total nitrogen removal rates during adjusted POR, areal removal rates for total phosphorus showed better correlation with influent P concentrations and loading rates. However, when LHLR was regressed against total nutrient removal, why was the R^2 value higher for nitrogen than phosphorus?*

Reply: Phosphorus is removed both through precipitation and algal production. Nitrogen, on the other hand is removed primarily through direct production of biomass on the ATS™. The stronger correlation between nitrogen removal and LHLR vs. nitrogen removal and N concentration or loading is likely due to the fact that LHLR directly influences algal production to a large extent, but likely has a reduced impact on phosphorus precipitation at the given floway length. Therefore, increased LHLR increases production, creating a better correlation with that element (N) whose removal is influenced solely by production. .

SECTION 6. GLOSSARY OF TECHNICAL TERMS

Accretion:	The gradual addition of new material on top of older sediments or soils.
Acre-foot:	The volume of liquid required to cover one acre to a depth of one foot.
Accuracy:	The closeness of measured values to the true value (as opposed to precision).
Advanced Treatment Technologies:	Biological and chemical treatment technologies designed to reduce phosphorus levels in stormwater.
Adverse impact:	The detrimental effect of an environmental change relative to desired or baseline conditions.
Allelopathic influence:	The inhibition of growth in one species of plants by chemicals produced by another species.
Algal Turf Scrubber (ATS™):	The proprietary ATS™ consists of a suitable substrate, typically plastic geomembrane overlain with an attachment grid, upon which nutrient enriched waters are discharged and an algal turf is cultured. The algal turf consists of dense mats of small anatomically simple periphytic or benthic algae less than several centimeters in height. Such turfs are effective at removing carbon dioxide, nutrients and a variety of pollutants found in natural or wastewater. Wave surge motion is typically incorporated into the ATS™ to enhance the exchange of metabolites between algal cells and the water medium.
Apical meristem:	The undifferentiated plant tissue from which new cells are formed, as that at the tip of a stem or root.
Benthic:	Bottom-dwelling, such as benthic insects.
Best Management Practices:	Land, industrial and waste management techniques that reduce pollutant loading from an industry or land use.
Biomass:	The weight of living material, usually as dry mass.

CERP:	Comprehensive Everglades Restoration Plan. A long-term series of more than 60 regional projects designed to restore the health, integrity and beauty of the South Florida environment. The plan was authorized as Title VI of the 2000 Water Resources Development Act and will vastly increase storage and water supply for the natural system, as well as for urban and agricultural needs while maintaining current Central and Southern Florida Project purposes.
Cubic hectometer:	A unit of measure (hm^3) used for large volumes and equivalent to 1,000,000 cubic meters (a cube 100 X 100 X 100 m).
Deaminase:	Any of a class of enzymes that catalyze the hydrolysis of compounds containing the amino group NH_2.
Decomposition:	The action of microorganisms causing both the breakdown of organic compounds into simpler ones and the release of energy.
Diquat:	A strong, nonpersistent, yellow, crystalline herbicide, $C_{12}H_{12}Br_2N_2$, used to control water weeds.
Discharge:	The rate of water movement, as volume per unit time (cubic feet or cubic meters per second).
Dissolved organic carbon:	The organic fraction of carbon in water that is dissolved (not filterable).
Evapotranspiration:	The process by which water is released to the atmosphere by evaporation from the water surface or movement from a vegetated surface (transpiration).
Flow:	The rate of movement of water, expressed as volume discharged from a source in a given time period.
Flow-weighted mean concentration:	The average concentration of a substance in water corrected for the volume of water flow at the time of sampling; samples taken when flow is high are given greater weight in the average. Flow-weighted concentrations can be used to calculate mass loading at a particular location.
Glyphosate:	Glyphosate is an organic solid of odorless white crystals. It is a non-selective herbicide used on many food and non-food crops as well as non-crop areas such as roadsides. When applied at lower rates, it serves as a plant growth regulator.

Invertebrates:	Small animals, such as insects, crayfish, mollusks and annelids, that do not have a backbone. These animals are often important components of ecosystem food webs and can be indicators of ecosystem health.
Loading (mass loading):	The mass of a material entering an area per unit time (e.g., phosphorus loading into Water Conservation Area 2A as metric tons per year).
Macrophytes:	Visible plants (e.g., sawgrass, cattails, sedges and lilies) found in aquatic environments.
Nutrients:	Elements that are essential as raw materials for the growth of an organism. In aquatic environments, nitrogen and phosphorus are important nutrients that affect the growth rate of plants.
Organochlorides:	Any of various hydrocarbon pesticides, such as DDT, that contain chlorine.
Organophosphorus:	Any of several organic compounds containing phosphorus, some of which are used as fertilizers and pesticides.
Parameter:	A variable or constant representing a characteristic of interest (e.g., conductance is a water quality parameter). Use of this term is highly subjective and varies greatly across disciplines.
Parts per billion (ppb):	Equivalent to one microgram per liter (µg/L).
Parts per million (ppm):	Equivalent to one milligram per liter (mg/L).
Parts per trillion (ppt):	Equivalent to one nanogram per liter (ng/L).
Periphyton:	The biological community of microscopic plants and animals attached to surfaces in aquatic environments. Algae are the primary component in these assemblages, and periphyton can be very important in aquatic food webs, such as those of the Everglades.
Phosphorus:	An element that is essential for life and can promote the growth of algae in water.
Quality assurance:	A program to provide a means for a product to meet a defined set of quality standards at a specified level of confidence.
Quality control:	Steps taken to ensure that quality standards are met.
Sheet flow:	The movement of water as a broad front with a

	shallow, uniform depth.
Species richness:	The number of species occurring in a particular area for a specified sampling period.
Stormwater Treatment Area (STA):	A large, constructed wetland designed to remove pollutants from stormwater runoff.
Supplemental technologies:	Advanced wastewater treatment techniques that have the potential to supplement STAs and reduce phosphorus to levels of about 10 ppb.
Total maximum daily load:	The maximum allowed level of pollutant loading for a water body to protect its uses and maintain compliance with water quality standards defined in the Clean Water Act.
Trophic level:	Distinct, definable levels at which groups of organisms are using or producing energy in Nature. Plants are the lowest trophic level and are the primary producers of biological energy. Grazing and detritus-feeding animals are in the intermediate trophic level. Predators such as bass, wading birds and raccoons are in the higher trophic level. Metals, such as mercury, accumulate at higher trophic levels, but most energy in Nature is stored in lower trophic levels.
Water Hyacinth Scrubber (WHS™):	The proprietary culture unit for the floating aquatic plant water hyacinth in which the unit is designed to optimize pollutant removal and biomass management.
Water quality standards:	State water quality standards are comprised of the beneficial use classification, the numerical criteria applicable to the classification, the Florida antidegradation policy, and several provisions in other rules.

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