HydroMentia, Inc.
HMI Water Treatment Technologies™

S-154 Pilot ATS™ - WHS™ Aquatic Plant Treatment System Final Report

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South Florida Water Management District

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FLORIDA DEPARTMENT OF AGRICULTURE
AND CONSUMER SERVICES
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EXECUTIVE SUMMARY

INTRODUCTION AND BACKGROUND

Lake Okeechobee is a large, multi-functional lake located within the Kissimmee-Okeechobee-Everglades aquatic ecosystem. The lake provides habitat for fish, birds, and other wildlife including a number of species classified as endangered or threatened due to losses of critical habitat.

Lake Okeechobee is listed under Section 303(d) of the Clean Water Act (40 CFR, Part 130) as a Florida impaired water body. The 1997 Lake Okeechobee Surface Water Improvement and Management (SWIM) Plan found that excessive phosphorous loading is one of the most serious threats to the lake. Documented adverse effects resulting from the increased internal and external phosphorus loading include more frequent algal blooms, changes in biological communities, and impaired use of the water resource. Concentrations of phosphorus in the lake have more than doubled the goal of 40 parts per billion (ppb) as established by the Florida Department of Environmental Protection (FDEP) through the Total Maximum Daily Load (TMDL) process.

The 1999 Lake Okeechobee Action Plan recommended that actions be taken to control external phosphorus loading from the lake watershed. The South Florida Water Management District (SFWMD) was charged with the responsibility of administering and providing funds through the Phosphorus Source Control Grant Program, which received funding from the State Water Advisory Panel through the FDEP. The grant program was intended to fund projects that have the potential for reducing external phosphorus loading emanating from the Lake Okeechobee watershed. The S-154 Pilot ATS™-WHS™ Aquatic Plant Treatment System was selected to receive funding through the Phase II of the Phosphorus Source Control Grant Program. Total project costs for the S-154 Pilot ATS™ -WHS™ facility are jointly funded by the SFWMD, FDEP, the Florida Department of Agriculture and Consumer Services (FDACS) and HydroMentia, Inc.

OBJECTIVES

The primary objective of the prototype facility is to evaluate the performance of the ATS™ - WHS™ Managed Aquatic Plant System (MAPS) for nonpoint source pollution control in the Lake Okeechobee Watershed (LOW).

Capable of operating under a wide range of conditions, the MAPS system was designed with significant flexibility to meet varying design objectives. Two operational procedures were assessed at the S-154 the prototype; (i) concentration reduction optimization, and (ii) nutrient load removal optimization. During the operational period January 27, 2003 through November 3rd, 2003 (Q1-Q3), assessment of the 2-stage (ATS™-WHS™) treatment system's ability to reduce the total phosphorus of S-154 surface waters to concentrations of 40 parts per billion or less was conducted. HydroMentia established the 40 ppb goal in the original project proposal based on the Lake Okeechobee TMDL 40 ppb in-lake total phosphorus concentration target. Based on the need to optimize phosphorus load reduction and phosphorus treatment costs in the LOW, during the operational period November 4, 2003 through October 18, 2004 optimization of phosphorus load reduction was assessed.

TECHNOLOGY AND FACILITY DESCRIPTION

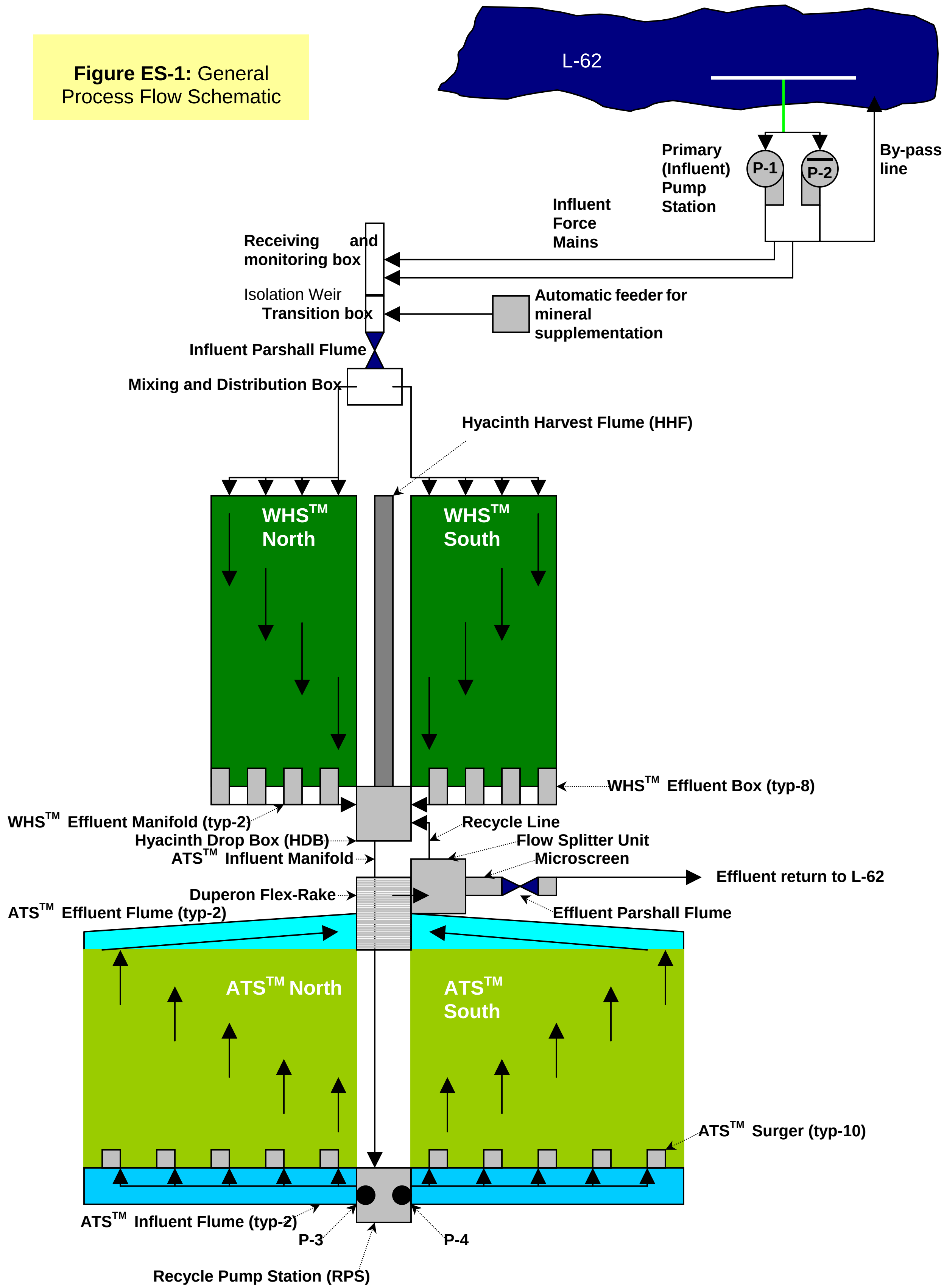
The study site is located one mile south of SR 70, west of the City of Okeechobee, east of the Kissimmee River, on property contiguous to the L-62 canal. The L-62 is the primary drainage canal for the S-154 basin located in the Lower Okeechobee Watershed. The site is an 18-acre parcel, which has been leased from the property Owner, Rio Ranch Corporation.

ATS™ - WHS™ system design and operation at the S-154 site is oriented around two primary unit processes in series as illustrated in Figure ES-1.

The first unit process, the Water Hyacinth Scrubber (WHS™) is composed of two equally sized, 4 ft deep, treatment cells of approximately 1.25 acres, that operate in parallel (WHS™ - North and WHS™ - South). These units are used to cultivate the floating aquatic plant, water hyacinth, through which phosphorus and nitrogen was removed from the water medium. Hyacinth biomass was recovered through periodic harvesting.

The second unit process is composed of two equally sized Algal Turf Scrubber® (ATS™) units of approximately 1.25 acres each. The ATS™ units are composed of an influent flume which receives water from the WHS™ units and delivers it to a series of flow surgers (five per unit). The surgers rely upon an automatic siphoning devise to deliver flows to the ATS™ units in surges in order to enhance algae production. The primary floway of the ATS™ unit is a flat sloping expanse over which is laid an HDPE geomembrane, and a nylon grid matrix. ATS™ - North is sloped at 2% grade for a length of 300 feet. ATS™ - South is sloped at 1.5% grade for a length of 300 feet. Flow is released via surgers to the ATS™. Water travels in a shallow laminar manner and is collected in an ATS™ effluent flume, designed to maintain velocities above 1.5 fps to facilitate recovery of sloughed and harvest solids.

Figure ES-1: General Process Flow Schematic



Biomass management within the WHS™ units is completed by mechanically removing plants from the treatment units and placing the hyacinth biomass in a centrally located Hyacinth Harvest Flume (HHF). Water flow within this flume conveys recovered biomass to a Hyacinth Drop Box (HDB) where the harvested biomass is removed by a conveyor system for further processing. Flow from the WHS™ treatment units are lifted by the Recycle Pump Station (RPS) to the second unit process – the ATS™.

After treatment by the ATS™ , flow from the ATS™ effluent flume moves into a central channel that is serviced by a Duperon Flex-Rake. The Flex-Rake removes the algae fibers from the water column. During Quarters 1-3, flow passed through the automatic rake, where it entered a splitter unit and a major portion of the flow was segregated for recycle back to the ATS™ system where it mixed with water coming from the WHS™. Recycling of ATS™ effluent was an operational approach introduced for the S-154 Pilot in an effort to optimize outflow cocntration within a limited ATS™ floway length. The remaining effluent flow was directed to a microscreen unit (10 micron), which removes residual solids prior to final metering, sampling and discharge back to L-62. Recycle of the ATS™ effluent was designed to allow reduction of phosphorus to achieve minimum effluent concentrations.

During Quarters 4-6, mean hydraulic flows to the ATS™-WHS™ system were increased by approximately 88.9%, while mean WHS™ and ATS™ treatment surface areas were reduced by 50% and 67.3%, respectively. This operational change was made in order to quanitfy the impacts of higher hydraulic loading rate to the two-stage system for the purpose of optimizing pollutant load removal for LOW surface waters within the hydraulic limitations of the existing facility. During this operational period, recycling of flows on the ATS™ was eliminated.

SYSTEM PERFORMANCE

Total Phosphorus

Concentration Reduction Optimization (Q1-Q3)

From Q1 through Q3 (January 27, 2003 to November 3, 2003), the system received 466.72 pounds of total phosphorus from a flow of 117.47 million gallons from the L-62 canal. Total phosphorus discharged with the system effluent was 74.88 pounds. Influent flow weighted, mean concentration of total phosphorus from weekly samples was 476 ppb ranging from 194 ppb to 770 ppb. The weekly concentration of effluent total phosphorus ranged from 30 to 200 ppb, with a flow weighted mean of 79 ppb overall. The percent removal for total phosphorus averaged 83.7%(Table ES-1)

During this period, hydraulic loading rate (HLR) was adjusted based on influent total phosphorus (TP) concentrations in order to optimize low effluent TP concentrations. While the S-154 Pilot ATS™-WHS™ system TP effluent of 79 ppb (83.7% removal) was less than the target TP concentration of 40 ppb, this may reflect the presence of a recalcitrant form of phosphorus within the L-62 source water. This was supported by performance of a parrallel study conducted by the University of Florida Institute of Food and Agriculture (IFAS) designed to investigate configurations for potential constructed wetlands systems in the LOW. Operating on the same source water as the S-154 ATS™ -WHS™ Pilot, the mean effluent TP concentration achieved for the 2-stage Cattail/SAV configuration was 169 ppb over 7 months of operation (FDACS, 2003).

Phosphorus loads to the system for the combined Q1, Q2 and Q3 period were lower than original projections due to HLR changes with increased influent concentration, and then decreased TP concentration toward the end of Q3. The phosphorus load for the first three quarters was 15.54 gm/m^2-yr, which is 81.3 % of the 19.12 g-P/m^2-yr projected load. Total phosphorus areal removal rate was 12.76 g-P/m^2-yr for this period as opposed to the projected 17.8 g-P/m^2-yr. Possible reasons for the differential in actual vs. projected concentration and areal removal performance are; a limit to the portion of phosphorus that is biologically accessible, as well as lower than projected phosphorus loading rate, which is described in greater detail within Section 5.

Table ES-1: Summary of system performance over the period of record (January 27, 2003 to October 18, 2004)

Operational Goal	**Concentration Reduction**		**Load Reduction**	
	Q1-Q3		Q4-Q6	
Operational Period	January 27 to November 3		November 3 to October 18	
Process Area (m^2)	18,431		8,526	
HLR (cm /day)	8.73		38.0	
Pollutant	**TP**	**TN***	**TP**	**TN***
Influent Concentration (TP= µg/l; TN= mg/l)	476	2.36	251	1.86
Effluent Concentration (TP= µg/l; TN= mg/l)	79	1.86	130	1.76
Areal Nutrient Loading Rate (g/ m^2-yr)	15.5	74	35.8	242
Areal Nutrient Removal Rate (g/ m^2-yr)	12.8	19.6 (84.3)	17.0	15.7 (148)
% Removal	84	26.4 (60.8)	47	1.0 (35.6)

*****Numbers in parentheses indicate removal values when supplemented nitrogen is included in analysis.

During the first three quarters, the WHS™ provided nearly 73 % of the system's total phosphorus treatment. Average areal total phosphorus removal rate for the WHS™ was 18.1 gm-P/m^2-yr. The ATS™ provided about 27% of the system's phosphorus treatment, with an average areal total phosphorus removal rate of 6.57 gm/m^2-yr.

Water quality data associated with this operational period is shown in Table ES-2.1.

Load Reduction Optimization (Q4-Q6)

During the load reduction study (Q4-Q6), the system received a total of 178.12 million gallons from the L-62 canal, and 500.4 pounds of total phosphorus. Mean weekly influent TP load averaged 11.2 pounds for the 3 quarters. Total phosphorus discharged with system effluent was 248.5 pounds equating to a removal of 251.8 pounds of phophsorus. Mean weekly effluent TP loads averaged 5.5 pounds effluent TP per week overall. The weekly flow weighted mean concentration of influent TP was 279 ppb and mean weekly effluent total phosphorus concentration was167 ppb (Table ES-1).

The combined Q4 through Q6 weekly removal for total phosphorus was 46.7%. For these quarters, average areal TP loading rate was 35.8 g-P/m^2-year. Average areal removal rate was17.0 g-P/m^2-year, a 33.2% increase over the Concentration Reduction Optimization Period. It should be noted that two hurricanes were experienced by the facility during Q6, causing power outages for a total of 31 days, thus reducing treatment capacity, as well as monitoring capabilities and disturbing the biological components of the treatment system. Overall, the system was able to maintain a high level of phosphorus removal when the HLR was increased by a factor of 4 from the first three quarters.

For the period, WHS™ phosphorus load was 47.6 g-P/m^2-year, with removal of 17.02 g-P/m^2-year. The ATS™ received 93.8 g-P/m^2-year and ATS™ removal was 21.5 g-P/m^2-year. These removal rates are consistent with those projected by the HYDEM model (used for the WHS™ process) and ATSDEM model (used for the ATS™ process) detailed in Section 5.

Based on ATS™ historical and project performance, and consistent with the project objective of optimizing MAPS design for a full-scale system in the LOW, the ATS™ was investigated as a possible stand-alone system. To accomplish this, three ATS™ floways were established independent of the

WHS™ treatment process, beginning in Q5. These flowways received water directly from the L-62 canal. The floways received various hydraulic loading rates in order to determine the optimal HLR for phosphorus removal in the LOW on an areal basis. As TP load is a function of HLR, TP load increased from the lowest to highest with respect to HLR on the independent floways. It was found that when TP load was 109 g-P/m^2-year, 157 g-P/m^2-year, and 397 g-P/m^2-year, corresponding ATS™ areal TP removal rates were 25 g-P/m^2-year , 47 g-P/m^2-year, and 92 g-P/m^2-year (HydroMentia, Inc., 2005).

Total phosphorus influent loading rate for the ATS™ in the main system was 93.8 g-P/m^2-year and is most closely comparable to that of the single stage floway receiving 109 g-P/m^2-year. This single stage floway showed removal of 25 g-P/m^2-year vs. 21.5 g-P/m^2-year for the main system ATS™. Influent TP concentration for the main system ATS™ was notably less than that associated with the single stage ATS™ (168 ppb vs. 336 ppb) due to pretreatment by WHS™. However, comparison of the two flowways provides indication that the ATS™ maintains high areal phosphorus removal rates regardless of influent TP concentration within this range. Performance of the main ATS™ and the single stage floways relative to STA TP removal is shown in Figure ES-2.

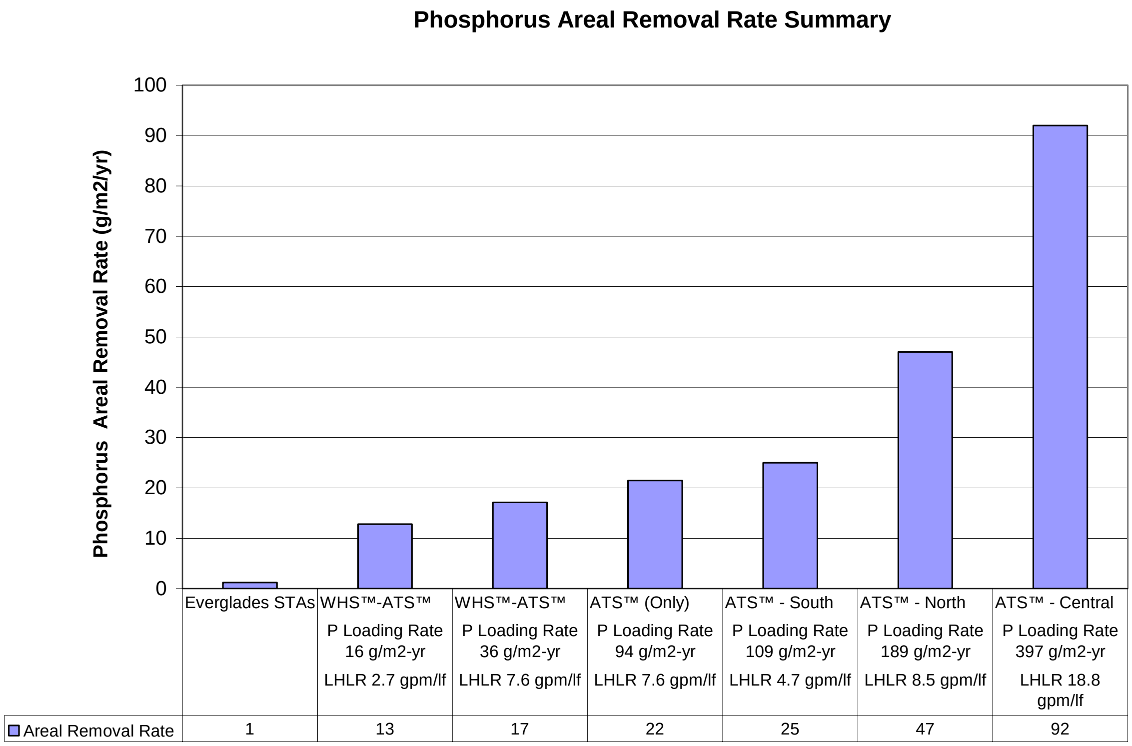
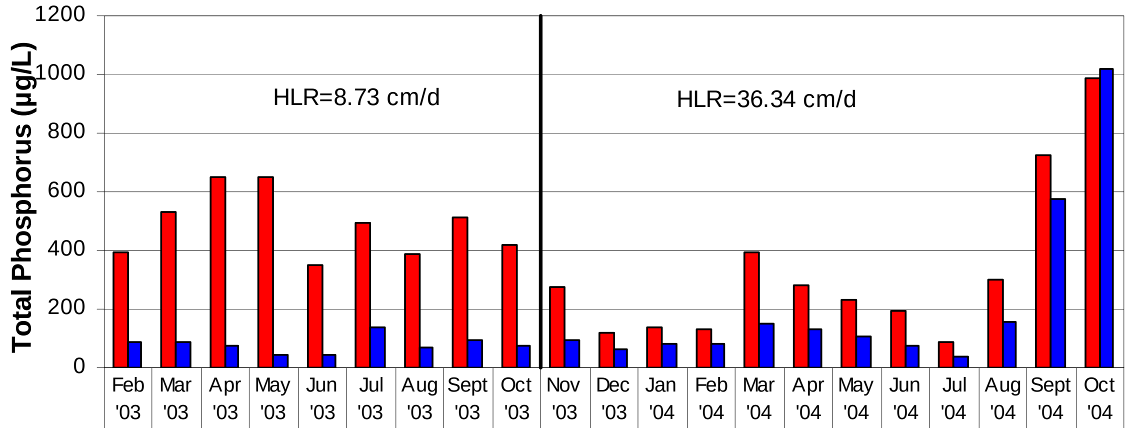


Figure ES-2: Summary of areal removal rate of Everglades STAs, S-154 pilot study ATS™-WHS™ System, and ATS™ Single Stage Floways.

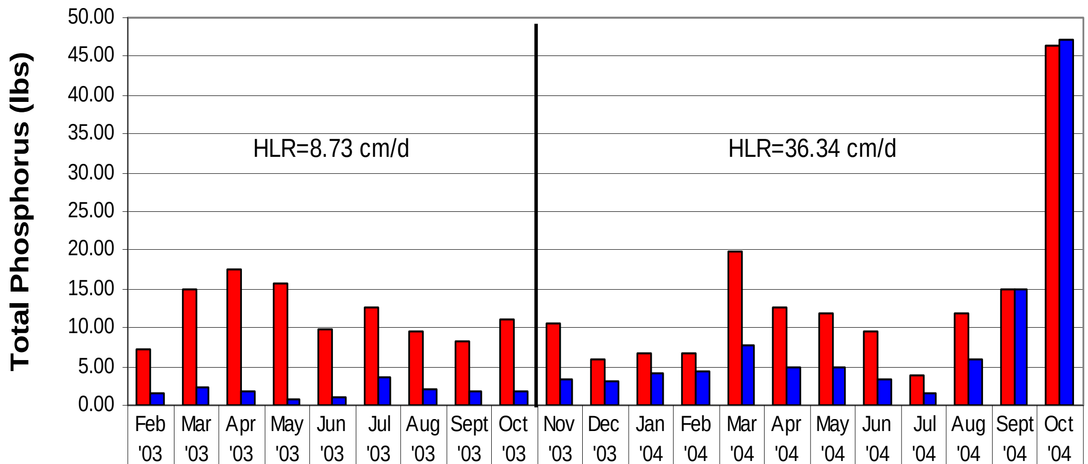
For Quarters 4 through 6, the WHS™ provided about 65.5% of TP removal, and 58% of ortho-P removal with respect to mass of nutrient removed. ATS™ contribution to total phosphorus removal was 34.5% and 42.0% for ortho-P. Of the 46% reduction in organic phosphorus by the entire system, the ATS™ provided 75% of this treatment. It is important to note that the ATS™ was reduced in area over this period to comprise only 17% of the system process area at the end of Q6. The area of the WHS™ remained at 5,060 m^2 while the ATS™ area was reduced from 3,616 m^2 to 1,021 m^2 . Thus, ATS™ contribution to removal is significant, despite its reduced size.

Water quality data associated with this operational period is shown in Table ES-2.1.



	Feb '03	Mar '03	Apr '03	May '03	Jun '03	Jul '03	Aug '03	Sept '03	Oct '03	Nov '03	Dec '03	Jan '04	Feb '04	Mar '04	Apr '04	May '04	Jun '04	Jul '04	Aug '04	Sept '04	Oct '04
Influent	393	529	653	649	352	491	385	513	420	275	117	135	130	396	280	234	192	89	302	725	987
Effluent	87	89	77	42	42	137	70	97	73	96	61	78	78	152	131	105	75	39.3	155	573	1021

Figure ES-3: Summary of flow-weighted total phosphorus concentrations for the S-154 Pilot ATS™ - WHS™ Treatment Facility.



	Feb '03	Mar '03	Apr '03	May '03	Jun '03	Jul '03	Aug '03	Sept '03	Oct '03	Nov '03	Dec '03	Jan '04	Feb '04	Mar '04	Apr '04	May '04	Jun '04	Jul '04	Aug '04	Sept '04	Oct '04
Influent	7.11	14.8	17.4	15.6	9.85	12.6	9.64	8.19	11.1	10.4	5.83	6.80	6.76	19.8	12.5	11.7	9.5	3.83	12	14.9	46.4
Effluent	1.51	2.42	1.78	0.86	1.13	3.71	1.94	1.87	1.85	3.25	3.00	4.24	4.27	7.73	5.02	4.86	3.34	1.56	5.9	14.8	47.3

Figure ES-4: Summary of flow-weighted total phosphorus loads for the S-154 Pilot ATS™ - WHS™ Treatment Facility.

Nitrogen

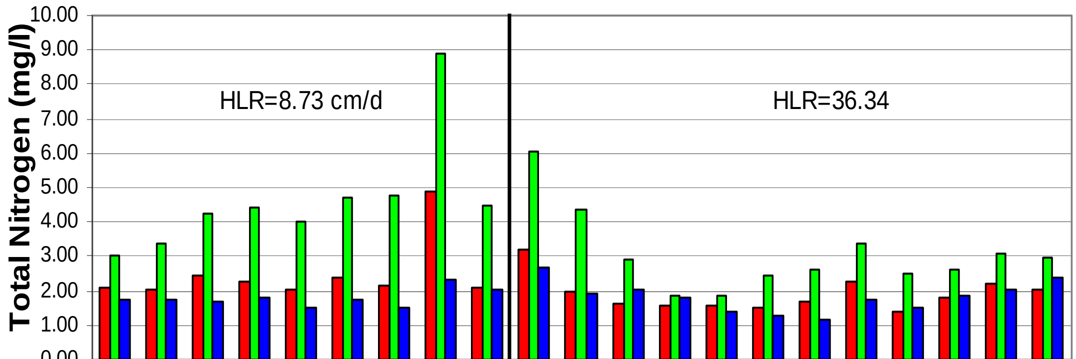
Concentration Reduction Optimization (Q1-Q3)

During the first three quarters, nitrogen dynamics of the system were dictated by a low average N:P ratio (5.53:1) within the L-62 impoundment surface water. As the N:P ratio within plant tissue is typically 8:1-15:1, there was indication that nitrogen would become the controlling element within a highly productive system. To optimize the system for phosphorus removal, 2,065 pounds of nitrogen were supplemented to the system during Quarters 1-3. During Q4 through Q6. 2,389 pounds of nitrogen were supplemented to the system, which totals 4,454 pounds of supplemented nitrogen for the period of record. In spite of this addition, there was still a net removal of nitrogen within the system, as noted within Figure ES-6. The N:P ratio within the effluent was increased to a flow weighted mean of 23.1 :1, a much more ecologically desirable level.

The system received 2,314.09 pounds of total nitrogen from the L-62 canal, with weekly loads ranging from 30.63 to 178.94 pounds (mean 57.2 pounds) for Q1-Q3. Mean supplemented influent load was 108 pounds per week . Weekly effluent TN load was 42.1 pounds per week. The weekly concentration of influent total nitrogen ranged from 1.10 ppm to 14.40 ppm, with a flow weighted mean of 2.36 mg/l. Weekly effluent TN concentration ranged from 0.82 mg/l to 3.37 mg/l with a flow weighted mean of 1.81 mg/l. Mean TN areal removal rate for Q1-Q3 was 84.32 g-N/m^2-year with a standard deviation of 38.93 g-N/m^2-year when taking supplemented nitrogen into account. Mean percent removal of TN was 26.4% from the L-62 canal water and 60.8% after supplementation.

Load Reduction Optimization (Q4-Q6)

During the loading rate study (Q4-Q6), the system received 4,131 pounds of total nitrogen. Weekly influent TN loads ranged from 40 to 319.54 pounds with mean influent load of 85 pounds per week from the L-62 canal. Total Nitrogen discharged with the system effluent was 3,751 pounds. Mean effluent TN load was 78.2 pounds ranging from 26.7 pounds to 142 pounds per week. Mean flow weighted weekly influent concentration was 1.86 mg/l ranging from 0.59 mg/l to 5.62 mg/l. Effluent mean TN concentration was 1.76 mg/l ranging from 0.60 mg/l to 3.58 mg/l. Average TN loading rate was 248 g-N/m^2-year from the L-62 canal or 377.5 g-N/m^2-year when considering supplemented nitrogen. Mean TN areal removal rate for Q4-Q6 was 148 g-N/m^2-year with a standard deviation of 119.7 g-N/m^2-year when taking supplemented nitrogen into account. Mean percent removal of TN was 1.0% from the L-62 canal water and 35.6% after supplementation.



	Feb '03	Mar '03	Apr '03	May '03	Jun '03	Jul '03	Aug '03	Sept '03	Oct '03	Nov '03	Dec '03	Jan '04	Feb '04	Mar '04	Apr '04	May '04	Jun '04	Jul '04	Aug '04	Sept '04	Oct '04
Influent	2.09	2.02	2.43	2.27	2.04	2.38	2.15	4.91	2.09	3.17	1.96	1.64	1.57	1.56	1.54	1.66	2.25	1.38	1.81	2.23	2.01
Adjusted Influent	3.00	3.39	4.25	4.43	4.01	4.72	4.75	8.92	4.48	6.06	4.33	2.89	1.89	1.87	2.46	2.62	3.35	2.49	2.64	3.09	2.98
Effluent	1.72	1.76	1.71	1.77	1.49	1.77	1.51	2.33	2.01	2.67	1.93	2.06	1.79	1.40	1.27	1.18	1.76	1.50	1.88	2.05	2.38

Figure ES-6: Summary of flow-weighted total nitrogen concentrations for the S-154 Pilot ATS™ - WHS™ Treatment Facility.

Presented in Tables ES-2.a and 2.b are the results of water quality monitoring during the quarter. Sampling of influent and effluent was done using a Sigma 600 Max refrigerated sampler on a flow rated basis, with a 70 ml sample taken for every 20,000 gallons of flow. Samples were recovered once weekly, with the last day's sample analyzed separately from a composite of the first six days. This was done to accurately assess parameters such as ortho phosphorus and nitrite nitrogen, which have a 24-48 hr holding time. Dissolved oxygen, water temperature, pH and conductivity were monitored continuously at each of the sampler station.

Table ES-2.a: Summary of water quality data for Concentration Reduction Optimization Period (Q1, Q2 and Q3).

Sample Type	Sample number	Influent	Effluent	Reported as
Total Phosphorus (ppb)	80	476	79	Flow weighted
Ortho-P (ppb)	78	352	23	Flow weighted
Organic-P (ppb)	78	124	56	calculated
TN (mg/l)	80	2.36	1.80	Flow weighted
N:P (ratio)	80	5.53:1	26.26:1	calculated
Water Temperature (ºC)	6,912	25.50	24.96	Arithmetic Mean
pH	13,745	6.78	8.58	Arithmetic Mean
Dissolved Oxygen (mg/l)	13,745	1.75	7.21	Arithmetic Mean
Conductivity micromhos	6,912	938	997	Arithmetic Mean
Nitrite Nitrogen (mg/l)	40	0	0	Arithmetic Mean
Nitrate Nitrogen (mg/l)	80	0.04	0.05	Arithmetic Mean
Total Organic-N (mg/l)	80	1.96	1.60	Arithmetic Mean
Ammonia-N (mg/l)	80	0.36	0.15	Arithmetic Mean
TKN (mg/l)	80	2.32	1.75	calculated
Calcium (mg/l)	78	34.30	33.63	Arithmetic Mean
Magnesium (mg/l)	78	16.16	16.08	Arithmetic Mean
Manganese (ppb)	15	48.9	57.0	Arithmetic Mean
Iron (mg/l)	56	1.18	0.33	Arithmetic Mean
Potassium (mg/l)	18	9.3	13.3	Arithmetic Mean
Sodium (mg/l)	18	92.3	76.9	Arithmetic Mean
BOD_5 (mg/l)	40	8.3	8.2	Arithmetic Mean
Alkalinity (mg/l) as $CaCO_3$	40	57	50	Arithmetic Mean
Total Dissolved Solids (mg/l)	40	620	619	Arithmetic Mean
Total Suspended Solids (mg/l)	40	9.8	3.2	Arithmetic Mean
Total Organic Carbon (mg/l)	40	32.4	29.5	Arithmetic Mean

Table ES-2.b: Summary of water quality data for Load Reduction Period (Q4 through Q6).

Sample Type	Sample number	Influent	Effluent	Reported as
Total Phosphorus ppb	135	278.75	167.08	Flow weighted
Ortho-P (ppb)	90	154.58	94.31	Flow weighted
Organic-P (ppb)	90	110.57	56.24	calculated
TN (mg/l)	45	1.86	1.76	Flow weighted-calculated
N:P (ratio)	45	10.41	20.44	calculated
Water Temperature C	4973	28.20	30.62	Arithmetic Mean
pH	9869	6.51	8.50	Arithmetic Mean
Dissolved Oxygen (mg/l)	9869	3.22	9.05	Arithmetic Mean
Conductivity micromhos	4973	808.42	883.42	Arithmetic Mean
Nitrite Nitrogen (mg/l)	90	BDL	BDL	Arithmetic Mean
Nitrate Nitrogen (mg/l)	90	0.08	0.17	Arithmetic Mean
Total Organic-N (mg/l)	90	1.59	1.55	Arithmetic Mean
Ammonia-N (mg/l)	90	0.15	0.04	Arithmetic Mean
TKN (mg/l)	101	1.83	1.59	Calculated
Calcium (mg/l)	73	33.00	33.23	Arithmetic Mean
Magnesium (mg/l)	73	15.72	15.73	Arithmetic Mean
Manganese (ppb)	0	-	-	Arithmetic Mean
Iron (mg/l)	0	-	-	Arithmetic Mean
Potassium (mg/l)	0	-	-	Arithmetic Mean
Sodium (mg/l)	0	-	-	Arithmetic Mean
BOD_5 (mg/l)	45	3.16	4.05	Arithmetic Mean
Alkalinity (mg/l) as $CaCO_3$	73	50.13	54.44	Arithmetic Mean
Total Dissolved Solids (mg/l)	73	566.46	539.58	Arithmetic Mean
Total Suspended Solids (mg/l)	73	7.34	6.64	Arithmetic Mean
Total Organic Carbon (mg/l)	73	26.31	26.19	Arithmetic Mean

In addition to reduction of phosphorus and nitrogen, the system also significantly enhanced dissolved oxygen (DO) levels, bringing the water into compliance with state standards. There was also a reduction in suspended solids from 8 to 4mg/l during the concentration reduction study. $BOD_5$was similar for Q1-Q3 influent and effluent, but rose slightly on effluent for Q4-Q6 (3.16 vs. 4.05 mg/l, respectively). Total Organic Carbon (TOC) remained nearly unchanged — (30 to 29 mg/l from Q1-Q3 and 26.3-26.2 from Q4-Q6). The pH was increased as a result of carbon dioxide uptake by the algae biomass, however the significance of this elevation was reduced as a result of the higher loading rate and discontinuation of recycling water through the system. There was little change in average water temperature, although the system experienced a wide diurnal variation in effluent water temperature, in addition to a corresponding variation in pH for the first three quarters. During the summer months of May, June, July and August, effluent daytime temperatures and pH values would on occasions reach above 40 C and 10.0, respectively during the first three quarters, though as stated this phenomena was less apparent in Q4 through Q6 where mean pH and temperature were essentially unchanged upon effluent.

BIOMASS HARVEST

Biomass harvests for the first three quarter period included 287.54 wet tons of hyacinths at 6.84% solids, and 0.46% phosphorus on a dry weight basis and 2.42% nitrogen on a dry weight basis. In addition, 74.25 wet tons of algal biomass was harvested at 5.77% solids and 0.53% phosphorus on a dry weight basis and 3.73 % nitrogen on a dry weight basis. The amount of phosphorus recorded as direct uptake into plant biomass, either as harvest or as a change in standing biomass, accounted for 300.75 pounds of phosphorus, or 75.8% of the total 391.84 pounds removed during the first three quarters from L-62, or 64.4% of the total incoming load from L-62. The amount of nitrogen recorded as direct uptake into plant biomass, either as harvest or as a change in standing biomass, accounted for 1,566.85 pounds of nitrogen, or 58.4% of the total 2,682.05 pounds removed during the period from the L-62 canal, including supplemented nitrogen, or 35.8% of the total incoming load from L-62 and supplemented nitrogen.

Biomass harvests for Q4 through Q6 included 311.55 wet tons of hyacinths at 5.19% solids, and 0.30% phosphorus on a dry weight basis and 2.13% nitrogen on a dry weight basis. In addition, 27.81 wet tons of algal biomass was harvested at 5.51% solids and 0.53% phosphorus on a dry weight basis and 3.63% nitrogen on a dry weight basis. The amount of phosphorus recorded as direct uptake into plant biomass, either as harvest or as a change in standing biomass, accounted for 78.21 pounds of phosphorus, or 33% of the total 238.6 pounds removed during these two quarters from L-62, or 14% of the total incoming load from L-62. The amount of nitrogen recorded as direct uptake into plant biomass, either as harvest or as a change in standing biomass, accounted for 632.2 pounds of nitrogen, or 23% of the total 2800 pounds removed during the period from the L-62 canal, including supplemented nitrogen, or 10% of the total incoming load from L-62 and supplemented nitrogen.

Biomass harvests for the period of record included 599 wet tons of hyacinths at 5.83% solids, and 0.4% phosphorus on a dry weight basis and 2.39% nitrogen on a dry weight basis. In addition, 92 wet tons of algal biomass was harvested at 6.17% solids and 0.55 % phosphorus on a dry weight basis and 3.8 % nitrogen on a dry weight basis. The amount of phosphorus recorded as direct uptake into plant biomass, either as harvest or as a change in standing biomass, accounted for 376 pounds of phosphorus, or 45% of the total 831.4 pounds removed during all 6 quarters from L-62, or 36% of the total incoming load from L-62. The amount of nitrogen recorded as direct uptake into plant biomass, either as harvest or as a change in standing biomass, accounted for 2,272 pounds of nitrogen, or 41% of the total 5504 pounds removed during the period from the L-62 canal, including supplemented nitrogen, or 20.6% of the total incoming load from L-62 and supplemented nitrogen. The nutrient balance summary for nitrogen and phosphorus for the six quarters as described by the concentration and loading rate studies are presented in Figures ES-7 and ES-8.

Most of the hyacinth harvest and some of the algae harvest were delivered to McArthur Farms as a "greenchop" feed ingredient. Throughout the period a group of heifers were fed up to 10 pounds per day, and accepted the material as part of their ration. Excess hyacinths and much of the algae residue was blended on site with hay and windrow composted. The compost developed as expected, with internal temperatures during composting exceeding 125^{o} F.

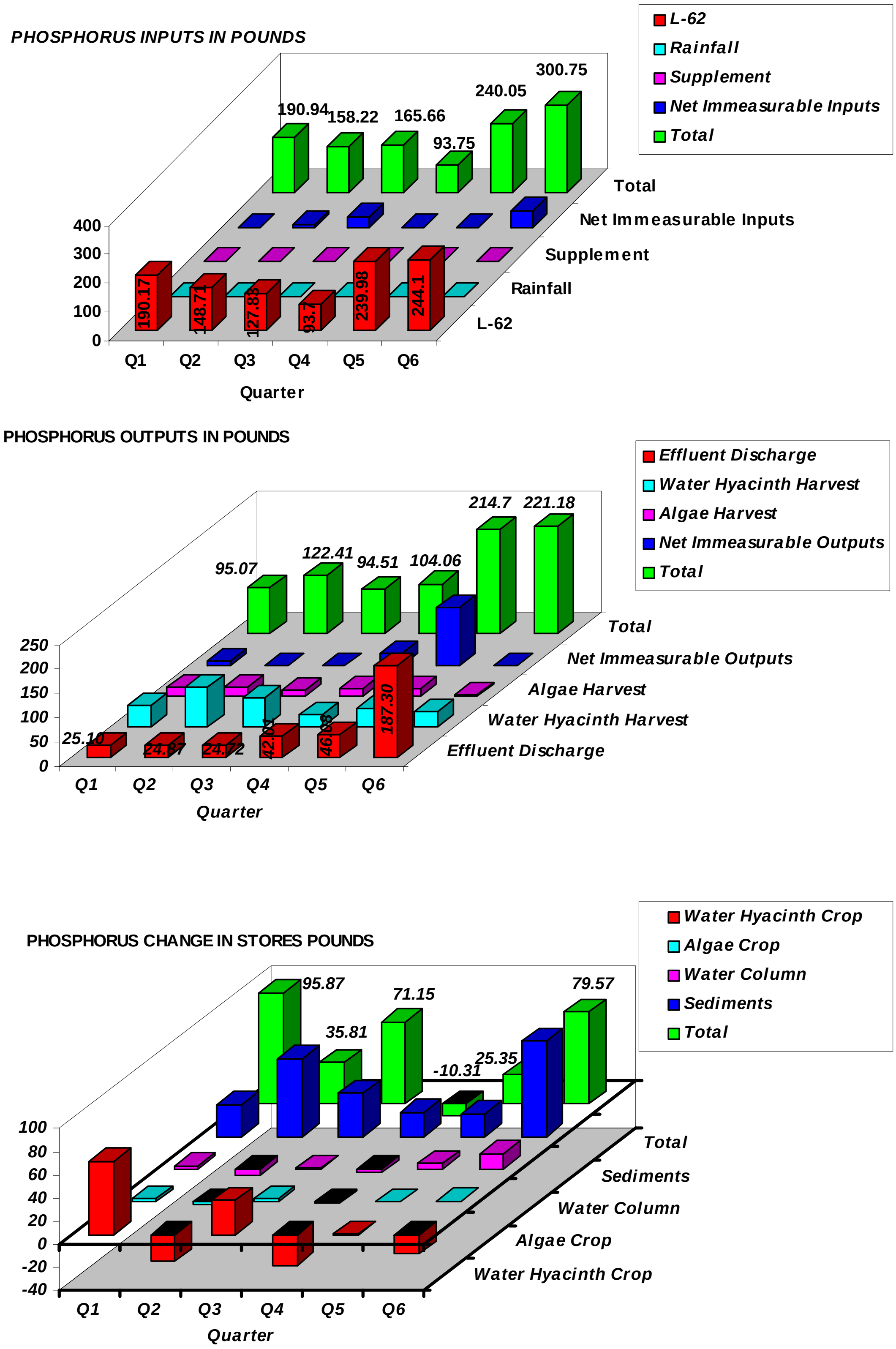


Figure ES-7: Phosphorus inputs, storage and outputs for the period of record.

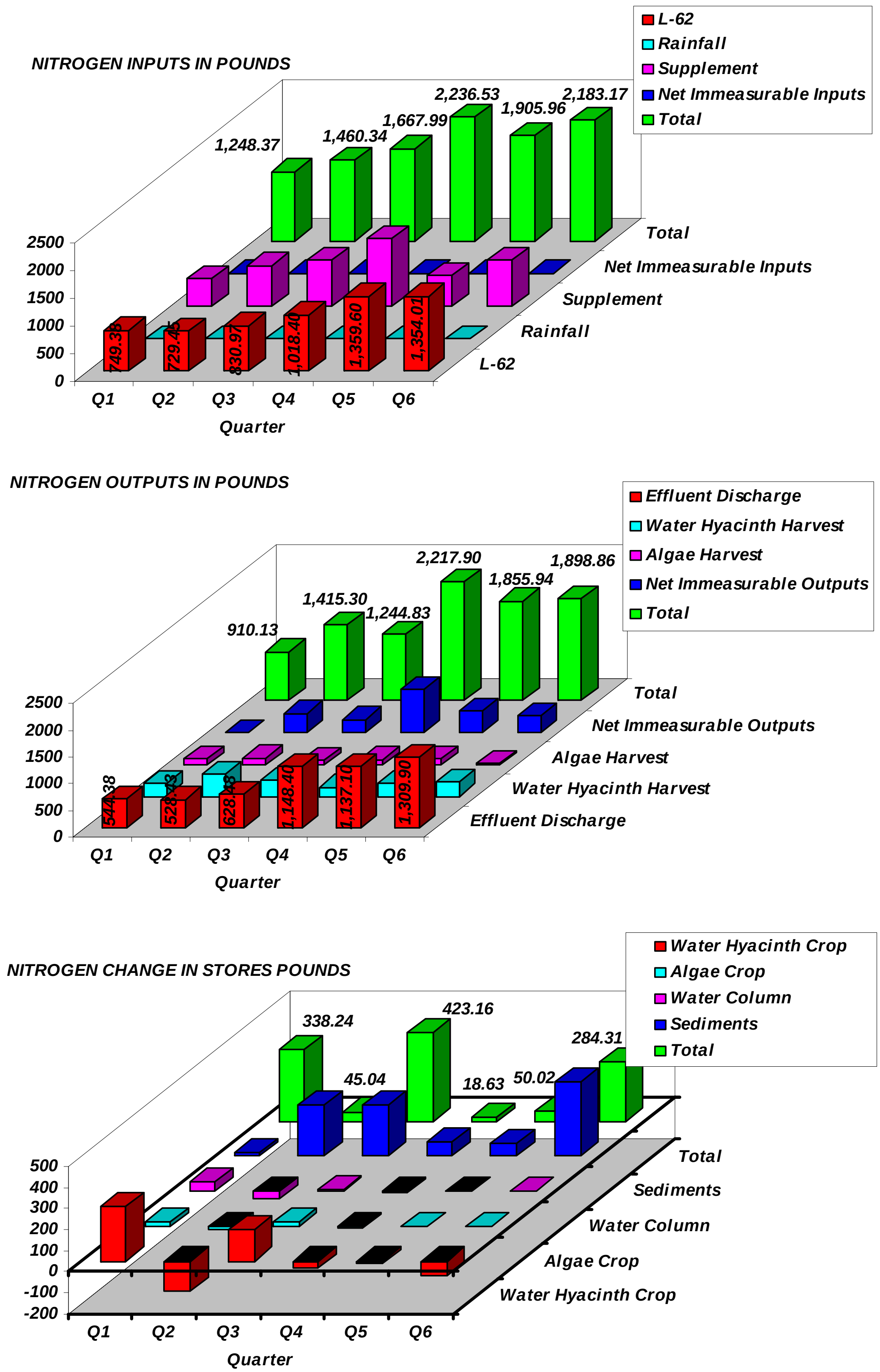


Figure ES-8: Nitrogen inputs and outputs for the period of record.

As noted in Figure ES-11, the system is demonstrating a close relationship between phosphorus loading rate and phosphorus removal rate. The intent of a loading based operation is to determine to what extent this relationship is maintained as incoming loads are increased to greater than 50 g-P/m^2-yr. Lower influent total phosphorus concentrations caused actual loads to be closer to 40 g-P/m^2-yr. While there is some autocorrelation in this analysis, it should be noted that system removal rates have increased during this high loading regime, and the contribution of the ATS™ to overall phosphorus removal has increased, as addressed in Section 2.

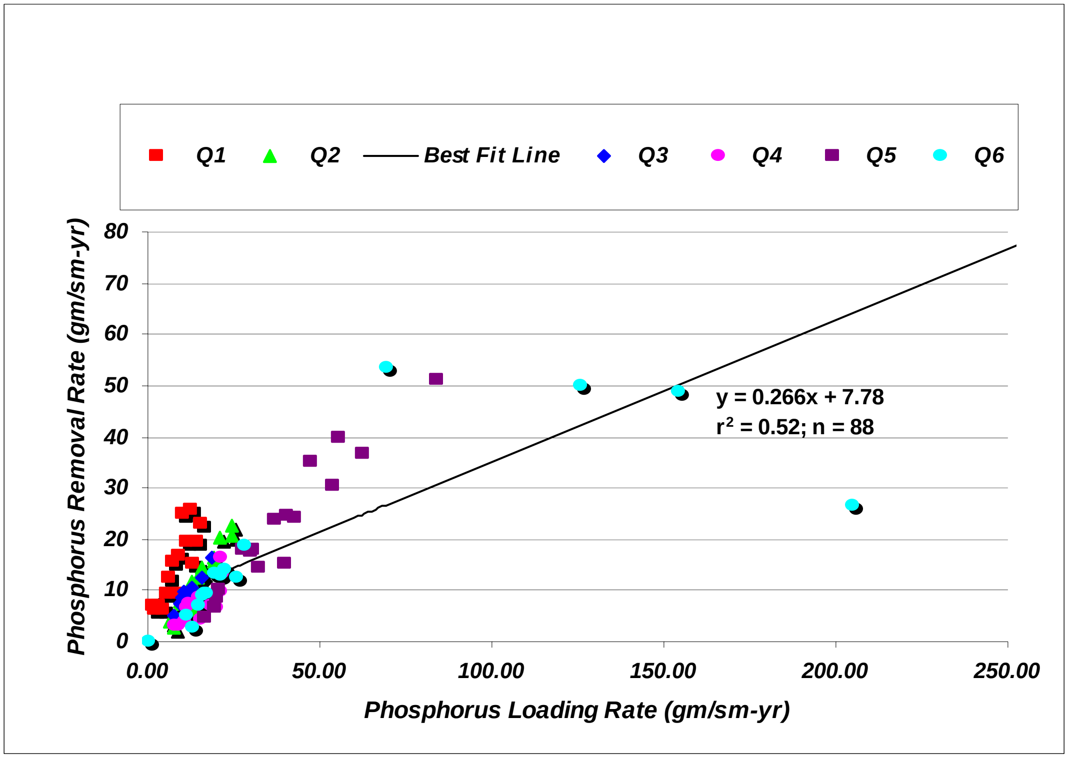


Figure ES-11: Phosphorus loading rate vs. phosphorus removal rate for 2-Stage ATS™ - WHS™ treatment system

SECTION 1. CONSTRUCTION COMPLETION AND START-UP

CONSTRUCTION AND EQUIPMENT INSTALLATION

Construction of the S-154 Pilot ATS™ - WHS™ Aquatic Plant Water Treatment System was initiated on June 14th, 2002 following completion of design, procurement of permits, and selection of contractors. The sitework contractor - Comanco Environmental Company of Baton Rouge, Louisiana, was issued a notice of substantial completion on November 6, 2002, and final completion on November 24, 2002. By December 2, 2002 all critical elements had been completed. By 1/31/03 all major equipment items, as listed within Table 1-1, had been received, installed, and tested.

Table 1-1. S-154 ATS™ -WHS™ Pilot Aquatic Plant Treatment System major equipment list

ITEM	MANUFACTURER OR FABRICATOR	FUNCTION	DATE RECEIVED	DATE INSTALLED AND TESTED
Primary Pumps, 2-7.5 HP Self Priming 350 gpm, 40 ft TDH	Gorman-Rupp/ supplier Hudson Pump	Continuous source water supply from L-62	10/1/02	11/27/02
Automatic Sampler 2-refrierated, programmable with flow, pH, DO, Conductivity probes	Sigma	Recover flow proportioned samples and record/store flows and water quality	8/2/02	11/27/02
Microscreen, 10 micron, 350 gpm capacity	Hydrotech/supplier WMT	Remove residual solids from Algal Turf Scrubber (ATS™) effluent	10/8/02	12/3/02
Hyacinth Conveyor	Aquamarine	Lift and feed harvested hyacinths into chopper unit	11/10/02	1/28/03
Hyacinth Grapple	HydroMentia, Inc /designed by Morgan Forage Harvesting /fabricated by Domers Inc.	Remove hyacinths from water hyacinth scrubber (WHS™) to harvest flume	1/20/03	1/27/03
Hyacinth Chopper	HydroMentia, Inc /designed by Morgan Forage Harvesting/fabricated by Domers Inc.	Volume reduction of harvested hyacinths	1/20/03	1/28/03
Volumetric Feeder	AccuRate	Chemical feed to WHS™ influent	10/9/02	11/27/03
Recycle Pumps 2-15 HP 1600 gpm, 24 ft TDH	MWI, Inc.	Lift hyacinth effluent and recycle flows to ATS™.	10/10/02	12/5/03
Automatic Flex Rake	Duperon, Inc.	Recover filamentous algae from ATS™ effluent	1/20/03	1/31/03

Initial testing of physical facilities commenced on December 2, 2002. Due to the temporary nature of the prototype facility, a number of concrete structures were partially constructed of block masonry to facilitate demobilization upon project completion. In several areas, excessive leakage from the masonry work was observed. Leakage was most severe around the recycle pump station, the ATS™ distribution box, the WHS™ harvest distribution box, and portions of the splitter box and dewatering bed. In most instances, application of a sealant coat was sufficient to mitigate this problem. However, differential settling around the ATS™ distribution box created more serious leakage, which was corrected by installation of an 80-mil HDPE liner within the box. The liner installation was completed December 27, 2002 and proved effective in eliminating leakage from the distribution box.

At the primary pump station, exposed sections of the suction line were encased in a 24 " HDPE pipe, and filled with sand bags to reduce vulnerability to vandalism (On January 6, 2003 the suction line was discovered shattered by gun shot). In addition, a no-flow shutoff switch was installed in the primary pump station discharge line, to ensure pump shut down in the event of flow loss, which protects the pumps and pump motors in the event of any future vandalism. On December 27, 2002 all critical systems were deemed suitable for full-scale operations.

Provided on the following pages are images of the S-154 Pilot ATS™ - WHS™ Aquatic Plant Treatment System and primary infrastructure components.

FACILITY IMAGES

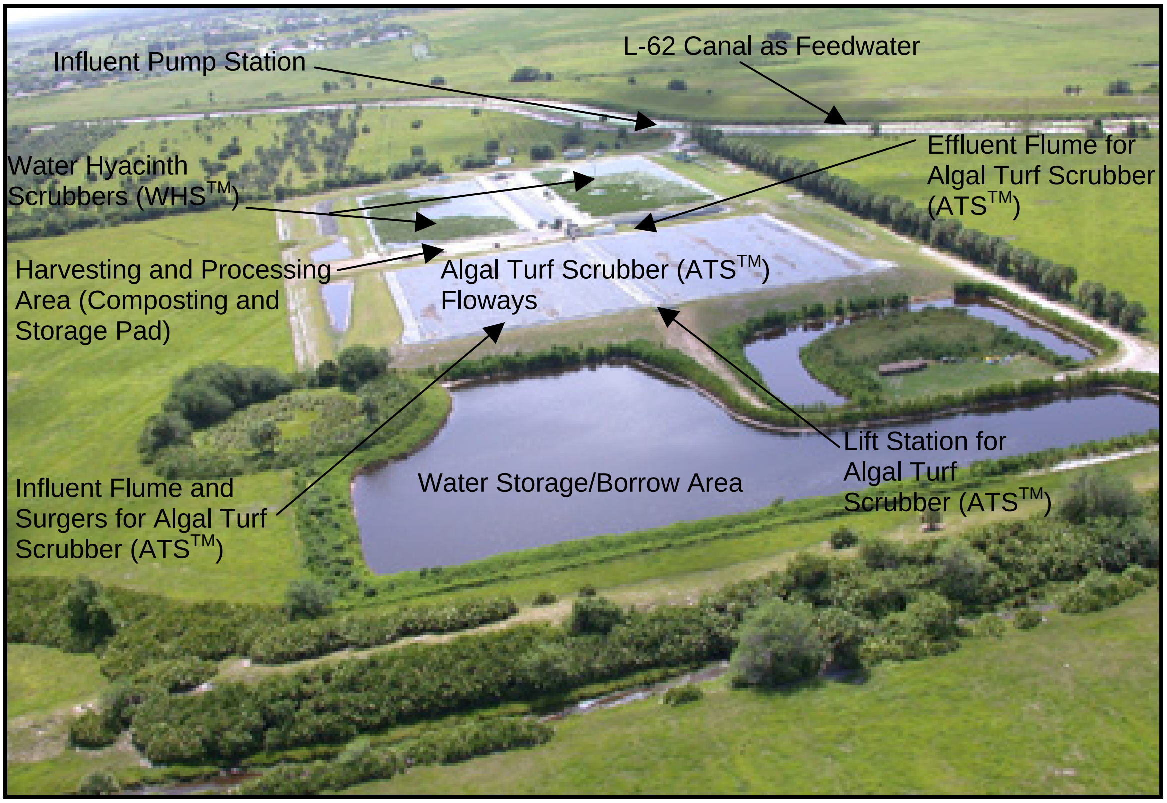


Illustration 1. Aerial photograph of S-154 Pilot ATS™ - WHS™ Aquatic Plant Treatment System

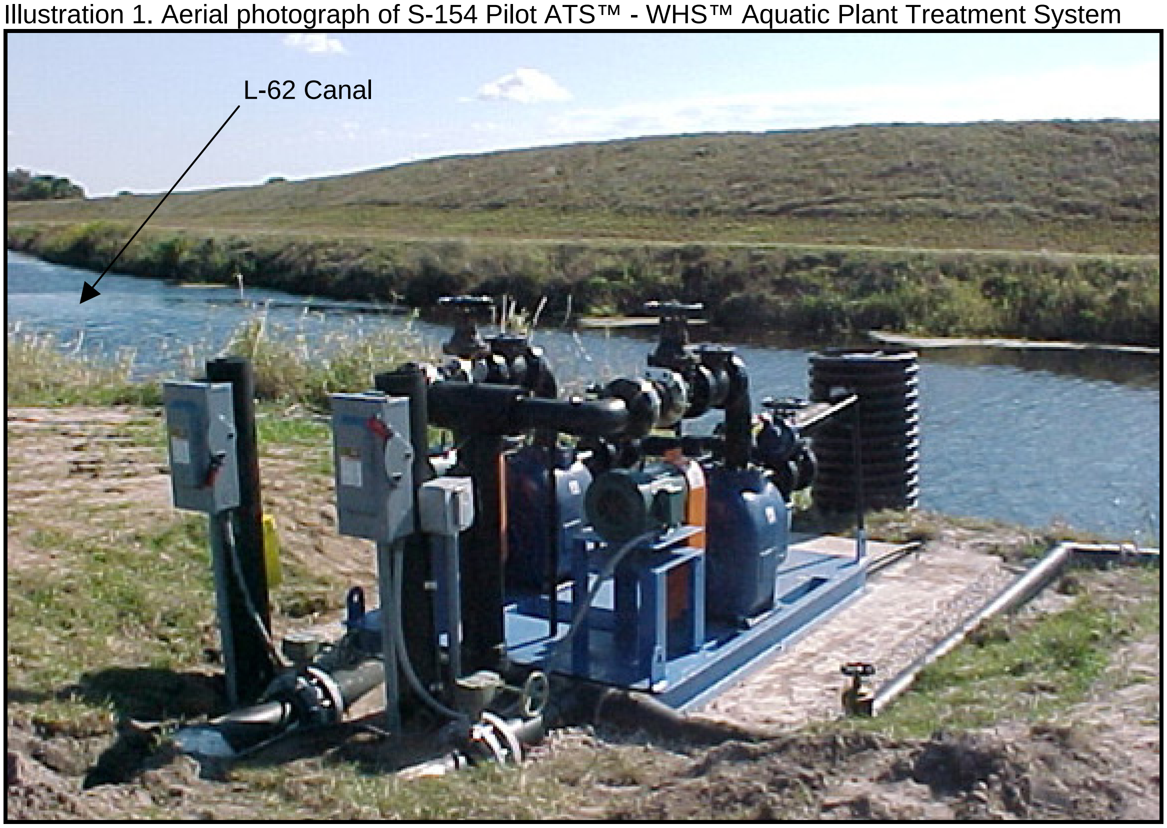


Illustration 2. System primary pump station.

Illustration 3. South WHS™ Treatment Unit in foreground. North WHS™ in background

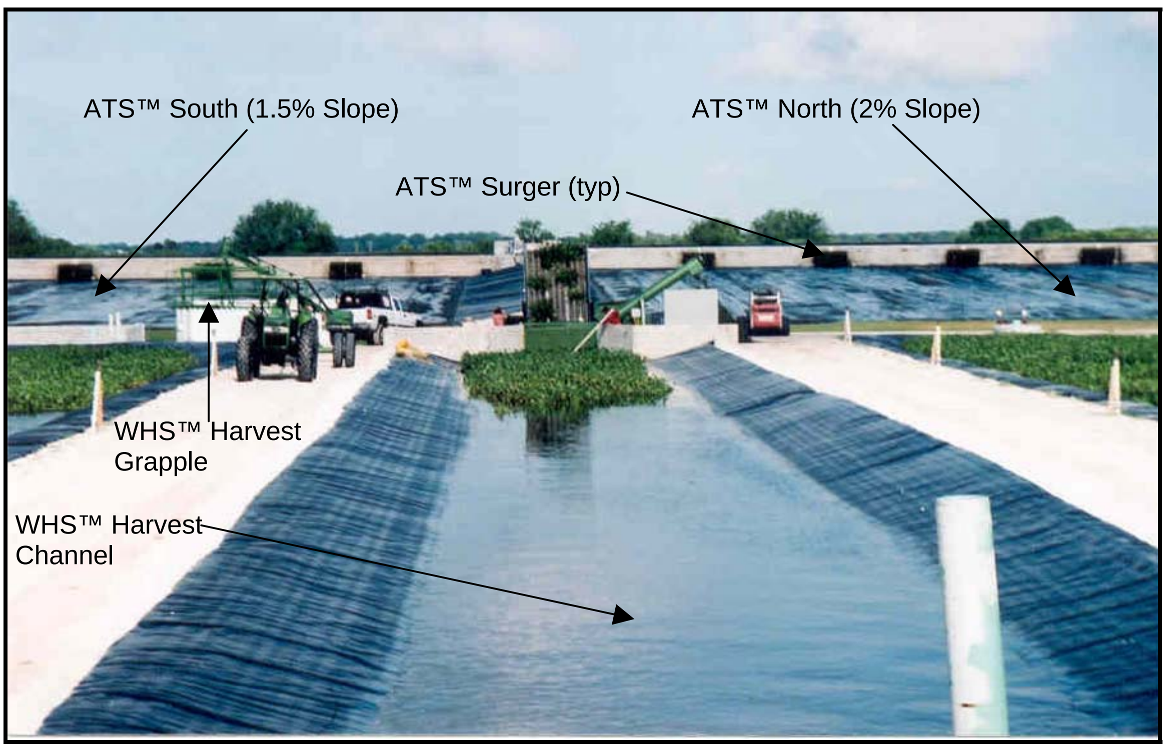


Illustration 4. WHS™ harvest channel

Illustration 5. Hyacinth biomass harvest

Illustration 6. Hyacinth biomass processing for livestock feed and compost

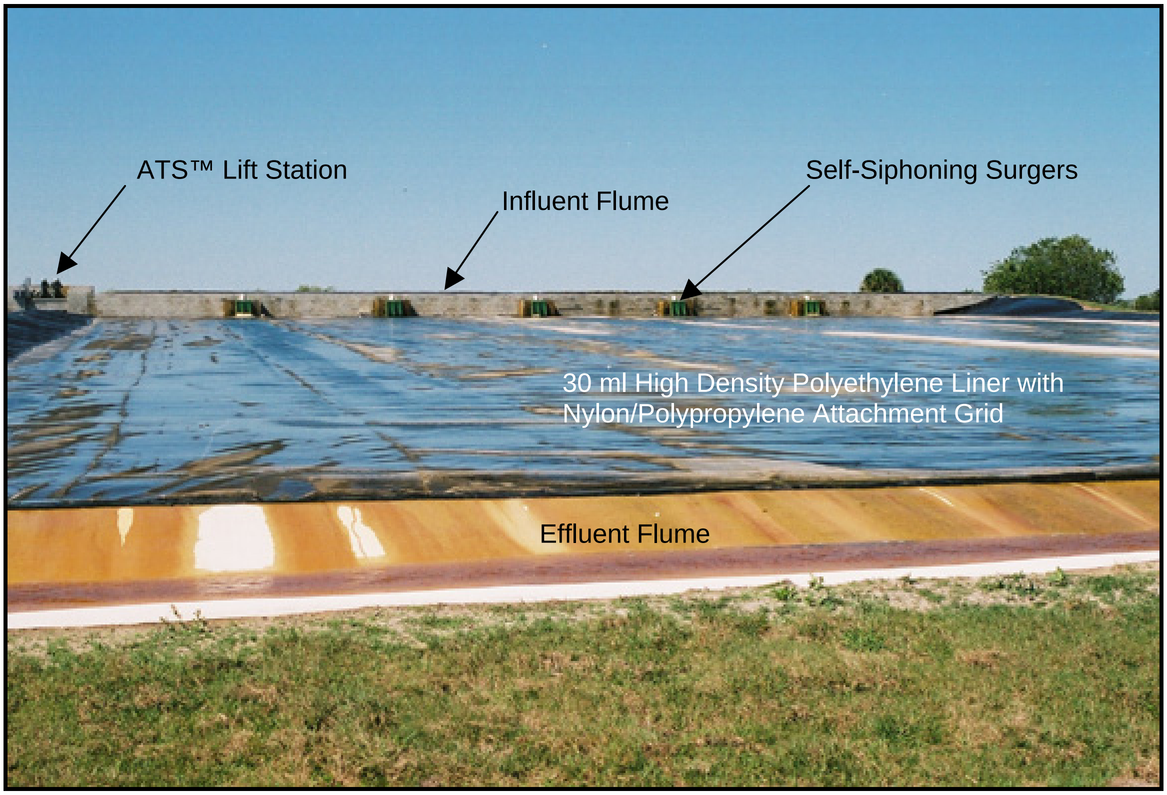


Illustration 7. View of North ATS™ Unit

Illustration 8. View of South ATS™ Unit

Illustration 9. ATS™ and WHS™ Biomass Recovery Station


Illustration 10. Hydrotech Model 1704 Discfilter (10 micron)

Illustration 11. Dense hyacinth biomass on WHS™ South (May 20, 2003)

Illustration 12. Filamentous strands of *Cladophora sp*. on ATS™

WATER QUALITY CONDITIONS

Prior to and during System Start-up, water quality conditions were established within the source water (L-62 impoundment), as noted within Table 1-2.The quality of water, as indicated through review of this data set, is congruent with the long term ranges associated with the L-62 impoundment, as presented within the Preliminary Engineering Report—Process Intent, submitted earlier to the District. The values represented are somewhat lower than the average values for L-62, but are generally within the expected ranges. The water quality in the winter months, which are characterized by low rainfall and runoff can typically be expected to be lower in nutrient and mineral concentrations, as well as organic pollution. The L-62 water may be classified as a relatively soft, nutrient enriched, neutral to slightly acidic, highly colored surface water. Field monitoring of dissolved oxygen levels provided indication that oxygen deprivation may be common in L-62. There is little evidence of extensive phytoplankton growth in the water, and the most prevalent plant within the water is the vascular floating plant, *Lemna minor*, or duckweed, although some submerged vegetation such as *Hydrilla and Ceratophyllum* are noted. The low alkalinity is likely related to a separation from deep groundwater sources. Most of the water within the system is associated with surface run-off and seepage from shallow groundwater. The low N:P ratio is typical of the run-off within the basins just north of Lake Okeechobee.

By the end of the Start-up period, flows were at about 200 gpm or nearly 60% of the design flow of 350 gpm. The total phosphorus reduction was from 460 ppb to 130 ppb, with ortho phosphorus being reduced from 360 to 100 ppb. Nitrogen was supplemented at about 13 pounds per week. There was a reduction in nitrogen from 1.82 m/l (pre-supplementation) to 1.72 mg/l, with the nitrogen being predominantly in the organic form.

BIOMASS DEVELOPMENT

The Water Hyacinth Scrubber (WHS™) was stocked in October 2002 with a starter crop of water hyacinths cultured at a HydroMentia owned facility located on 4550 NW 240th Street, Okeechobee, Florida. Plants were transported from the HydroMentia facility located about 20 miles north of the S-154 facility as authorized under Aquatic Plant Permit #1940 as issued by the Florida Department of Environmental Protection. Approximately 11 tons of wet biomass was placed within the S-154 WHS™ facilities. Equal amounts were placed in the two scrubber units. Each unit has a water surface area of approximately 1.25 acres, and an average depth of 3.5-4.0 feet. The starter crop had been cultivated in greenhouses, and provided necessary nutrient and mineral supplementation. When the plants were transferred they were free of insect pests and disease.

For a period of approximately two months the hyacinth biomass was allowed to develop within the WHS™ units under static conditions, i.e. without a continuous flow of water. To prevent nutrient depletion, nitrogen, calcium, magnesium, and iron were supplemented. In addition, make-up water was added from L-62 to the system intermittently. By December 9, 2002 the hyacinth biomass had developed to 50 wet tons, of which 79.24% was viable tissue (40.33 wet tons). The calculated growth rate over this period was 0.019/day, which is consistent with projections presented within the Preliminary Engineering Report of 0.017/day. Some infestation by the hyacinth weevil (*Neochetina eichhorniae)* was noted shortly after stocking. (The hyacinth weevil has become ubiquitous in south Florida, and is capable of flying considerable distances to locate its host plant).

By January 27th the hyacinth biomass had expanded to 92.74 wet tons, or 60.28 wet tons viable tissue at 65% viable tissue. Distinction is made between total weight and viable weight in an effort to track and document the relative health of the hyacinth crop. Significant changes in the percent viable tissue provide early indication of changes in plant health. Such changes are typically related to pest infestation, disease, nutritional deficiencies or imbalances, other water quality issues such as pH or salinity, crowding, or competition.

Table 1-2. Influent Water Quality from the L-62 Impoundment at ATS™-WHS™ System Start-Up

Date	**12/9/02**	**12/9/02**	**12/9/02**	**12/16/02**	**12/16/02**	**12/23/02**	**12/23/0**	**Design Range**
Sample Type	24 hr Composite* *	Weekly Composite **	Grab	Weekly Composite **	Grab **	Weekly Composite **	Grab	From Preliminary Engineering
Total Phosphorus ppb		100	110	100	81		210	608 (SD=459)
Ortho-P (ppb)			BDL		13		140	
Organic-P (ppb)			110		68		70	
Nitrate-N (mg/l)	.029	0.03		0.06	BDL	0.018	0.047	
Nitrite-N (mg/l)	BDL				BDL		BDL	
Total Organic-N (mg/l)	1.04			1.41	1.20	1.50	1.20	
Ammonia-N (mg/l)	0.06	0.13		.09		BDL	BDL	
TKN (mg/l)	1.10	1.30		1.51		1.52	1.20	
TN (mg/l)	1.13	1.33		1.57		1.54	1.25	1.78 (SD=059)
N:P (ratio)		13.3		15.7			6.0	4.03 (SD=3.22)
Calcium (mg/l(	48				46		47	35 (SD=19)
Magnesium (mg/l)	23				23		22	17 (SD=11)
Manganese (ppb)			10		3.3		4.7	
Iron (mg/l)	0.86				0.59		0.53	1.61 (SD=0.50)
Potassium (mg/l)			8.6		8.9		10	9 (SD=3)
Sodium (mg/l)			130		140		140	
Sulfur (mg/l)			30.3		25		24	
Copper (ppb)					3.7		4.6	
Selenium (ppb)			BDL		BDL		BDL	
Zinc (ppb)			3.1		3.6		1.4	
Boron (ppb)			81		86		87	
BOD_5 (mg/l)			BDL		BDL			
Alkalinity (mg/l) as $CaCO_3$		57	52			54		45 (SD=15)
Total Dissolved Solids (mg/l)					790		730	
Total Suspended Solids (mg/l)							BDL	8 (SD=12)
Total Organic Carbon mg/l					23		25	
Organophosphorus pesticides			ND					
Organochloride pesticides			ND					

** Weekly composites are flow weighted for six days, the 24-hour composite is flow weighted on the seventh day, being the last day before pick-up.

The Algal Turf Scrubber (ATS™) biomass development was initiated once flow was continuous across the two 1.25 acre ATS™ treatment units. At commencement, no effort was made to "seed" the floway with algae, although later some filaments of the green algae *Cladophora sp.* were transported from the WHS™ to the ATS™. While turf development proceeded at first at what was considered an expected pace, it faltered shortly thereafter. An assessment program was initiated to identify and quantify those factors that might be inhibiting algae production. These included pH, flow energy, nutrient and micronutrient deficiencies, and allelopathic influences. A detailed discussion of this exercise is included in Section 4.

At time of full System Start-up algal biomass was minimal. The decision was made however to proceed with full-scale operations in an effort to remain on schedule and to initiate operational procedures.

REVIEW OF ADJUSTMENTS

The physical/mechanical aspects of the facility required the following adjustment during and just after the Start-up period. These included:

- Placement of no-flow shut-off switch at primary pump station, and piping adjustments on by-pass line and suction line to protect the pumps from power outages, vandalism, or excessive suction pressures which would be caused by clogging of the intake manifold.
- Adjustment of ATS™ influent surgers to set surge volumes.
- Placement of larger orifice inlets to surgers at ATS™ influent to accommodate a two-pump flow rate.
- Set recycle rate using two recycle pumps (about 3000 gpm) to increase hydraulic energy and coverage on the ATS™ floways.
- Adjustments to chemical feed as required tosatisfy the pH adjustment and nutrient/micronutrient needs of both the algae and water hyacinth crops. This issue is discussed in detail in Section 4.
- Placement of filter cloth over sand media in dewatering bed to reduce contamination of collected organics with sand, thereby allowing a more accurate quantification of solids captured by the microscreen.
- Adjustment of hydraulic by-pass from the microscreen channel to reduce overflow from the splitter unit.
- Install water-cooling system for protection of bearings within the recycle pump station. This was done by MWI - the pump manufacturer.

SECTION 2. WATER QUALITY AND TREATMENT PERFORMANCE

OBJECTIVES

The primary objective of the prototype facility is to evaluate the performance of the ATS™ - WHS™ Managed Aquatic Plant System (MAPS) for nonpoint source pollution control in the Lake Okeechobee Watershed (LOW). Two operational procedures were assessed at the S-154 the prototype; concentration reduction optimization, and nutrient load removal optimization. During the operational period January 27, 2003 through November 3rd, 2003 (Q1-Q3), assessment of the 2-stage (ATS™-WHS™) treatment system's ability to reduce the total phosphorus of S-154 surface waters to concentrations of 40 parts per billion or less was conducted. During the operational period November 4, 2003 through October 18, 2004 optimization of phosphorus load reduction in order to obtain the lowest possible cost per pound of phosphorus recovered, was assessed.

More specific objectives were to:

- Determine the viability of the pilot through consistent demonstration of phosphorus reduction capabilities based on concentration and load reduction.
- Establish a viable pilot scale ATS™ - WHS™ treatment system, defined as a process train of two primary unit processes, the first being two identical and parallel water hyacinth scrubber treatment units (WHS™) represented by lined plug flow lagoons, the second and following being two Algal Turf Scrubber® (ATS™) treatment units operated in parallel, with one ATS™ set at a slope of 2%, the other at 1.5%, both composed of water distribution components and a high density polyethylene (HDPE) sloped surface over which is lain a nylon type fabric, which receive pulsing flow in a shallow laminar manner. The area was reduced to one WHS™ lagoon and one ATS™ (1.5% slope) unit during the load reduction study of the project.
- To establish the capability of cultivating targeted aquatic plants, namely the floating vascular plant the water hyacinth (*Eichhornia crassipes* [Mart] *solms*) and a collection of periphytic algae known as Algal Turf, with cultivation to include crop maintenance, harvesting and processing.
- To verify and/or determine the critical design and operational criteria required to maintain this viability, to include such factors as nutrient and hydraulic loading rates, recycle rates, ancillary equipment and process needs, product value and general capital and operational costs per unit of treatment capacity.
- To establish the particular operational needs associated with flows attendant with the S-154 basin so specific design conditions can be identified for system expansion.
- Ultimately to allow objective assessment of the ATS™ - WHS™ technology and its applicability in providing cost effective and sustainable phosphorus reduction within the S-154 basin, and similar applications within the boundaries of the South Florida Water Management District (SFWMD).

To share findings with other entities involved in development and evaluation of long term nutrient control programs for large-scale water resources.

MONITORING PERIOD / PERIOD OF RECORD (POR)

The first quarter (Q1) through fourth quarter (Q4) and the extended contract (January 27, 2004 through October 18, 2004), herein referenced as the fifth and sixth quarter or Q5 and Q6, operations and monitoring period or period of record (POR) for the S-154 ATS™-WHS™ Pilot Water Treatment Facility was January 27th though October 18th, 2004. Data reported within this text and the corresponding data collection periods are as follows, these dates corresponding to the end of the sampling week on Monday at 9:00 AM.

MONTH	MONITORING PERIOD
February:	January 27 to March 3 = 35 days
March:	March 3 to March 31 = 28 days
April:	March31 to May 5 = 39 days
	Q1 = 99 days
May	May 5 to June 2 (excluding May 11) = 27 days
June	June 2 to June 30 = 28 days
July	June 30 to August 4 = 36 days
	Q2 = 91 days
August	August 4 to September 1 (excluding Aug 29-31) = 25 days
September	September 1 to October 6 (excluding Sep 1-2)= 33 days
October	October 6 to November 3 = 28 days
	Q3 = 86 days
November	November 3 to November 30 =27 days
December	November 30 to December 28 =28 days
January	December 28 to January 25 (excluding Dec 21-23) = 25 days
	Q4= 80 days
January	January 25 to February 1 = 7 days
February	February 1 to February 29 =28 days
March	February 29 to March 28 = 28 days
April	March 28 to May 2 (excluding April 6-8) = 32 days
May	May 2-May 31= 29 days
	Q5 = 124 days
June	June 1 to June 28 = 28 days
July	June 28 to July 26 =27 days
August	July 26 to August 30 (excluding August 35) = 33 days
September	August 30 to September 27(excluding Sept. 3-14)= 16 days
	September 27 to October 18 (Excluding Sept. 27- Oct 13) = 15 days
	Q6 = 119 days
	Q1 + Q2 + Q3+Q4+Q5+Q6= 599 days

The WHS™ - ATS™ system proceeded through maturation and stabilization period during much of the first quarter, consistent with other managed aquatic plant based treatment systems (MAPS). Consequently, nutrient removal rates were influenced by the development of the hyacinth and algal turf biological systems. By the end of the first quarter and for the first 8 weeks of the second quarter the system was operated as a mature system, and accordingly, demonstrated high level of performance. For the remainder of the second quarter, a disruption, possibly of external origin, resulted in a decline in performance, with recovery noted during the final two weeks of the second quarter. A detailed and objective review of the nature and impacts of this disruption and potential factors contributing to its development is presented later within this section.

During the second quarter, data monitoring and operational capabilities were lost on one day (May 11, 2003) due to a power outage. Because this power loss resulted in the absence of in-situ data, failure of the automatic sampling capabilities, and the inability to utilize the ATS due to loss of the lift pumps, this day was not included in this review, nor was it considered an operational day.

During the third quarter the influent pump station was shut down due to application of herbicides within L-62 by the District staff on August 29-31, and September 1 and 2. During this period influent samples were not collected, and the days are not considered fully operational days.

During the fourth quarter, the influent pump station was shut down due to herbicide application in the L-62 canal by District staff from Dec. 19-21, and Dec 23. Influent samples were not collected at this time, and the days are not considered fully operational days.

During the fifth quarter, the influent pump station was shut down from April 5 through April 8, 2004 to perform construction at the ATS™ site for the independent ATS™ floways. Influent samples were not collected at this time, and the days are not considered fully operational days.

Due to an extremely active storm season during Quarter 6, the system was without power for a total of 31 days. A lightning strike on August 25, caused power outage for 2 operational days. Data collected for the time period May 31-August 25 by the autosampler was lost due to this strike. Additionally, Hurricanes Frances and Jean caused power outages for the dates September 3 to 14, and September 27 to October 13, respectively. The facility suffered no operational damage other than the power outage, and the effects of these storms on water quality will be discussed later in this section.

Data presented in the reports submitted for the Q1-Q5 period for flow, conductivity, pH, and temperature were based on hourly values collected by system autosamplers (Sigma 900 Max). The August 25 lightning strike and subsequent power outages prevented this method of sampling for much of Quarter 6. However, as noted in earlier reports, hand held metering device (Hydrolab) data generated throughout the project have generally followed the same trends as autosampler data. Thus, Hydrolab data and field collected flow data based on autosampler readings is presented for these four parameters for Quarter 6 within this report.

The initial primary objective of the S-154 WHS™ -ATS™ -(MAPS) Prototype Water Treatment Facility was the reduction of total phosphorus concentrations from the S-154 Basin (L-62 Canal) to below 40 ppb as specified in the Project Proposal and Operations and Maintenance Plan. Due to the short (12-month) duration of the project, operations of the WHS™- ATS™ treatment system were conducted with the intent of achieving the lowest possible total phosphorus discharge concentration within the present system configuration for the first three quarters. After these first 3 quarters, the primary objective was replaced with an effort to optimize the system for total phosphorus load reduction.

During the beginning of quarter four and through quarter six, operational adjustments were made by increasing flow rates and reducing treatment area to optimize the system for areal removal rates, i.e. load reduction. An eight-month extension was granted to the project for this load reduction study, in addition to the investigation of three independent ATS™ floways, which received feed-water directly from L-62. The results from the operations and monitoring of these independent flowways are included within a separate report.

ASSESSEMENT OF DISRUPTIVE EVENT

From May 5, 2003 through June 30, 2003, the system produced an effluent ranging from 30 ppb total phosphorus to 55 ppb total phosphorus, with an average effluent concentration of 39 ppb. The percent removal was 91.2%, with an areal loading rate of 15.07 g-P/m^2-yr and an areal removal rate of 13.73 g-P/m^2-yr.

Following June 30, 2003 to July 28, 2003, the system produced an effluent ranging from 87 ppb total phosphorus to 200 ppb total phosphorus, with an average effluent concentration of 141 ppb. The percent removal was 70.7%, with an areal loading rate of 16.35 g-P/m^2-yr and an areal removal rate of 11.50 g-P/m^2-yr. This latter period represents a significant loss of performance, and was also characterized by a noticeable loss of the algae crop as well as a loss of water hyacinth biomass. The influence of one or more changes within the system, which triggered these perturbations, whether from internal or external causes, are referenced within this report as a disruptive event. Throughout the remainder of this report the impact of this disruptive event may be noted within the various tables and figures, as well as within the general discussion.

There was recovery of system performance noted through Q3, Q4 and Q5. During this review of the disruptive period references will be made to various tables and figures in the body of the report. Review of these is helpful in clarifying the nature, influences and sequences of the various identified changes associated with this disruptive event.

Included in Table 2-1 is a general chronology over Q2 in which are noted critical changes in key parameters. The critical changes may be summarized as follows:

Temperature patterns within the effluent as noted in Table 2-1 and as shown graphically within Figures 2-4 and 2-13, indicate a general rise in temperature as expected, from May through July. Maximum temperatures at the end of the ATS™ floway rose to above 40 C during the daytime on occasions.

The pH patterns tracked temperature to an extent, with all three months showing maximum pH levels above 10.0. The pH trends are noted in Table 2-1 and Figures 2-33 through 2-38. The indication based upon review of data is that June showed higher peak pH levels than May, with more data points over 10.0 within the effluent. Peak pH levels in June were only marginally different than July, with approximately 3% more data points over 10.0. Acid addition to the system was reduced on June 16 from 20 to 17 gallons per day, but was returned to 20 gallons per day on July 7. This change did not appear to solicit a significant change in pH trends, as is noted within Figure 2-32. During the 21-day period of reduced acid addition, the number of pH data points exceeding 10.0 was less than the prior 21-day period.

On the morning of June 25 the District staff was observed spraying the entire length of the L-62 canal, including next to, and in the vicinity of the L-62 intake line as part of normal District vegetation management procedures. It was thought initially only the herbicide glyphosate was being applied, but later it was disclosed that diquat was also being used. Diquat is noted to be deleterious to filamentous algae. A series of email and written correspondence was associated with this event, and with later changes in the system.

Glyphosate was found in small quantities in two of the three grab samples taken. Diquat was undetected in all three samples.

The hyacinth system showed a drop in productivity during the week of 6/2/03. A review of the available minerals indicated a possible deficiency of copper. After consulting with Dr. J. Benton Jones[1], HydroMentia commenced with copper addition to the hyacinth system on 6/16/03. Production responded favorably, until 7/7/03, when extensive biomass loss was noted. Hyacinth contribution to phosphorus removal was noted to drop some during the week ending 6/2/03, although it recovered and remained stable until the week ending 7/14/03, at which time it dropped dramatically from 16.3 g-

1 Dr. J. Benton Jones, Jr. is one of the foremost authorities in the world on plants and plant nutrition. The author of four books and 200 articles on the subject, Dr. Jones is a certified soil and plant specialist and holds the position of Professor Emeritus at the University of Georgia. He was the editor of two international agronomy journals and is currently a Fellow of the American Association for the Advancement of Science, the American Society of Agronomy, and the Soil Science Society of America. Dr. Jones is also president of Benton Laboratories, a consulting firm, and HydroSystems, Inc.,

P/m^2-yr on 7/14/03 to 3.3 g-P/m^2-yr on 7/21/03 to below 1.0 g-P/m^2-yr for the remaining two weeks of the quarter. During the following month of August (first month of Q3) the removal rate had returned to an average of 16.6 g-P/m^2-yr, reaching 28.6 g-P/m^2-yr on September 1, 2003.

The hyacinth crop showed signs of extensive tissue loss and sloughing, but did not show any morphological signs of stress or deficiencies. The algae crop remained rather stable until 6/30/03, at which time extensive sloughing and necrosis became evident. Microscopically, extensive cellular lysing was observed.

The algae sloughing was documented as harvest via the Microscreen, causing a noticeable imbalance in productivity numbers related to floway coverage when compared to harvest. The ATS™ filamentous algae percent cover dropped rapidly during the first week of July. Phosphorus removal rates associated with the ATS™ remained relatively high until 7/21/03. Total phosphorus removal dropped from 84 to 97% from 5/12/03 through 7/14/03, to 44.5%, 33.6% and 62.6% for the last three weeks of Q2.

Dissolved oxygen levels were very low in the influent, averaging 0.16 mg/l throughout Q2 until 7/7/03, at which time the suction line was removed from the bottom and suspended about 4 feet below the surface using a float system. For the remainder of the period, the influent DO averaged 0.64 mg/l. Low oxygen conditions prevailed in the WHS™ as noted in Figure 2-45, improving somewhat in July, possibly because of the improved DO levels within the influent.

During the week of 7/21/03 the hyacinth crop was separated, in an effort to reduce crop density and enhance productivity. This activity likely contributed to tissue sloughing and some biomass reduction during this period.

Loss of algae was noted not only on the floways during early July, but also on the surging devices, and more importantly at the influent discharge point within the WHS™. HydroMentia personnel also noted that there was some loss of algae within some of the receiving chambers associated with the DB Environmental on-site research units. These observations gave some indication that at least one causative agent was associated with the L-62 influent.

In early September the District again conducted routine spraying of herbicide in the L-62 as part of normal District vegetation management procedures, and this time HydroMentia temporarily restricted influent flow. No loss of algae or hyacinth crop has been observed.

There is insufficient data to make conclusive statements about the cause(s) of the disruptive event. There is some indication that toxic influence was associated with the L-62 influent. This may be associated with the herbicides; with toxic substances associated with the bottom sediments or water column; or other items. The general increase in heat and pH stress also could be contributory to the event. It is important to include provisions within any future systems to avoid or alleviate these possible stresses. These should include ensuring influent water that has been exposed to recent applications of herbicides not be introduced into the treatment system until the water is tested and proven free of herbicides, or an appropriate waiting period has been observed. This was done during the third quarter, as noted, on the dates August 29-31,September 1-2, December 19-21 and December 23, all in 2003.

In conjunction with subsequent routine District herbicide applications in the L-62 canal conducted as part of normal District vegetation management procedures, inflow to the WHS™ - ATS™ water treatment facility were temporary interrupted. No impact to the District's aquatic plant control program was experienced, while impacts to routine operations of the WHS™ - ATS™ treatment systems were negligible.

Table 2-1: Chronology of key parameters monitored during Q2

Week Ending 2003	5/12	5/19	5/26	6/2	6/9	6/16	6/23	6/30	7/7	7/14	7/21	7/28	8/4
Average daily effluent flow mgd	0.31	0.34	0.45	0.55	0.43	0.41	0.48	0.45	0.42	0.38	0.52	0.48	0.42
Influent TP ppb	770	756	324	262	351	435	350	365	582	751	375	255	194
Effluent TP ppb	33	55	37	38	36	30	53	52	87	120	200	142	74
Total System TP loading rate g/m^2-yr	20.8	24.2	11.4	9.5	13.0	15.4	12.6	12.7	19.1	24.2	13.9	7.7	6.2
Total System TP Removal rate g/m^2-yr	20.2	22.8	10.1	7.9	11.8	14.5	10.7	10.9	16.4	20.7	6.2	2.6	3.9
WHS™ TP Removal rate g/m^2-yr	33.2	34.7	10.7	6.7	13.0	14.8	8.6	10.6	15.5	16.3	3.3	0.76	0.32
ATS™ TP Removal rate g/m^2-yr	4.3	8.4	9.4	9.3	10.4	14.1	13.3	11.3	17.5	26.1	9.7	4.8	8.2
System % TP Removal by mass	96.8	94.2	89.1	83.5	91.1	94.1	85.1	86.1	85.7	85.8	44.5	33.6	62.6
Rainfall inches	0	0	1.3	4.5	0.3	0.8	1.9	0.4	0	0	1.3	4.7	0
Average Air T ^{O}C	27.0	27.0	24.7	25.0	26.2	26.8	25.5	26.2	27.0	27.5	26.6	26.0	26.0
Average Effluent T ^{O}C	27.9	27.3	26.0	26.6	27.5	28.7	27.0	27.5	28.3	28.7	28.6	27.9	28.4
Maximum Effluent T ^{O}C	39.3	39.9	40.1	39.4	39.4	40.3	37.0	37.7	38.9	38.9	40.3	40.7	40.3
Average Effluent pH	8.8	8.7	8.8	9.0	9.0	9.0	8.9	9.1	9.1	9.0	9.1	9.1	8.9
Maximum Effluent pH	10.1	10.2	10.2	10.5	10.6	10.4	10.4	10.4	10.6	10.2	10.4	10.6	10.5
Acid added gal/day	20	20	20	20	20	20	17	17	17	20	20	20	20
Nitrogen added lb/week	52.9	52.9	52.9	52.9	52.9	52.9	58.3	58.3	57.2	61.2	61.2	61.2	61.2
Iron Sulfate added lb/week	95	95	95	95	95	49	60	89	63	105	105	105	90
Hyacinth Standing Crop viable wet tons	167	151	146	116	136	124	150	162	160	145	122	121	113
Hyacinth Harvest wet tons	10.1	13.4	14.1	11.7	4.5	6.8	5.9	5.5	7.1	8.0	7.4	10.3	7.1
Hyacinth Specific Growth Rate 1/day	0.024	-0.004	0.005	-0.024	0.027	-0.007	0.015	0.015	0.003	-0.009	-0.018	0.007	-0.003
Algae production by coverage dry g/m^2/day	2.18	2.48	4.26	3.37	5.66	2.51	2.69	4.40	0.76	0.77	0.13	1.00	2.10
Algae production by harvesting dry g/m^2/day	1.22	1.05	1.42	2.15	1.93	1.55	1.57	0.99	0.62	8.17	0.93	11.41	0.79
Algae Harvest by Rake dry lbs	102	132	125	170	234	239	205	178	155	79	42	28	0
Algae Harvest by Microscreen dry lbs	22	24	0	12	36	8	13	25	1.4	1,013	0	90	301
Comments	5/11/03 Power Outage, microscreen in hand mode for 5 days 6/16 0.29 lb/week of copper sulfate added to hyacinths when low growth noted after consulting with Dr. Jones. 6/23 reduced acid to 17 gal/day. Dredge crews placing trench along access road. 6/25 District spraying in L-62 in AM. Grab samples taken for herbicide testing from L-62 for three consecutive days. 6/27 Vandalism—two ATV stolen 7/4 Algae crop noted to be deteriorating, considerable sloughing 7/7 Extensive loss of algae, with associated clogging of overloaded microscreen. 7/7 L-62 Suction line removed from bottom and floated 7/7 Note canal level dropping over previous week to 20.5 ft from 23,5 7/14 Microscreen clogging and algae sloughing continuing 7/21 Canal level recovering, possibly because of back pumping by the District. 7/21 Hyacinth crop spread out to reduce density 8/4 Some recovery noted with algae												

ANALYSIS OF FLOWS

To accommodate the developing WHS™ and ATS™ treatment units during the first quarter, which had not yet reached maturation, initial flows were held at about 200 gpm, or about 60% of the 350 gpm design flow. As biomass within the treatment systems developed and pollutant load reduction improved, flow rates were increased accordingly. By the week of March 17, 2003 the system flow had been increased to the design flow of 350 gpm, or 0.50 MGD. The operation was held at or near this rate until April14, 2003.

As a result of elevated phosphorus concentration in the L-62 source water during the end of March and beginning of April 2003, phosphorus loads to the ATS™-WHS™ Treatment System exceeded design projections based on post-stabilization conditions. Accordingly, in an effort to sustain low total phosphorus concentrations within the effluent, an operational decision was made to reduce flows to lower phosphorus loads to design projections. It was projected that this adjustment would result in a reduction to the desired effluent concentration of 40 ppb total phosphorus. Flows after that period were set at about 300 gpm or about 0.43 MGD or about 86% of design flows. By mid-May, again in an attempt to approximate design flows, the flow was again increased to near 350 gpm, and remained at this level until the third week of July, when the impacts of a disruption became evident. At this time, influent flow was reduced to about 300 gpm in an effort to reduce phosphorus load discharges. The lower flows were continued through mid-September, after which flows were increased to near design flows.

In early November 2003, operational objectives changed from optimization for phosphorus concentration reduction to optimization for phosphorus load reduction. This required increasing flow to the system by modifying the design flow to about 700 gpm or 1.0 MGD. Additionally, the operational treatment area was reduced in order to further increase phosphorus loads to the system.

During this time, no adjustments were made for phosphorus concentration, and effluent water was discharged from site after one pass through the ATS™, with recycling of ATS™ flows and acid addition being eliminated. In the fourth quarter, mean inflow was 584 gpm or 0.841 MGD. The fifth quarter mean flow rate was 608 gpm or 0.876 MGD. The sixth quarter mean flow rate was 485 gpm or 0.698 gpd. It should be noted that the median flow for the sixth quarter was 0.802 gpd. Noted within Figure 2-1 and 2-2 are the system flow patterns for the period of record.

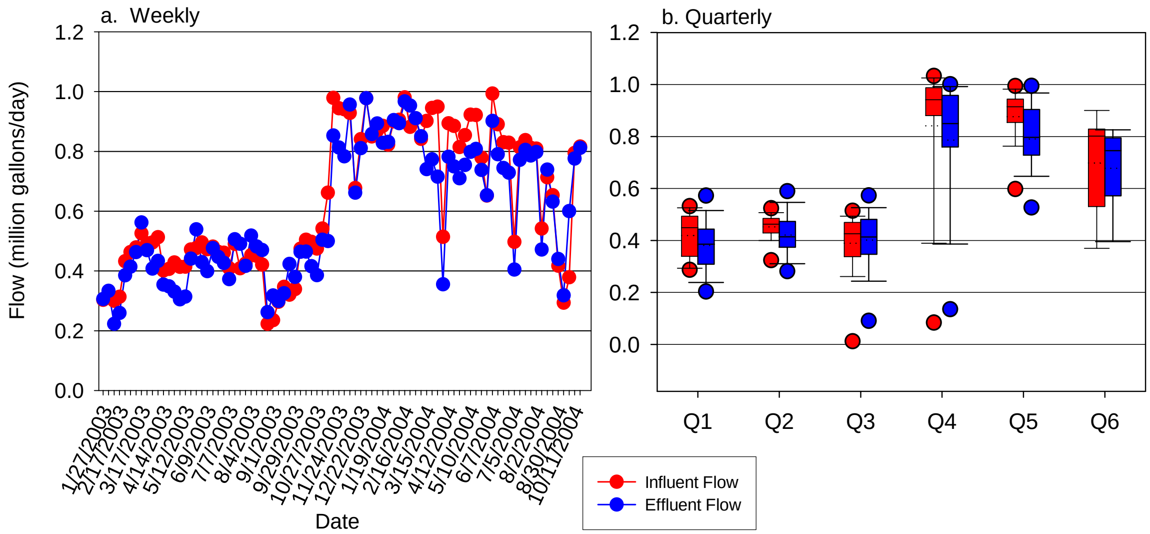


Figure 2-1. Influent and Effluent flows for the period January 27,2003, through May 31,2004. Figure a. Mean weekly flow. Figure b. Flow by quarter with 5th and 95th percentile ranges. Dotted horizontal line represents mean flow. Solid horizontal line represents median flow.

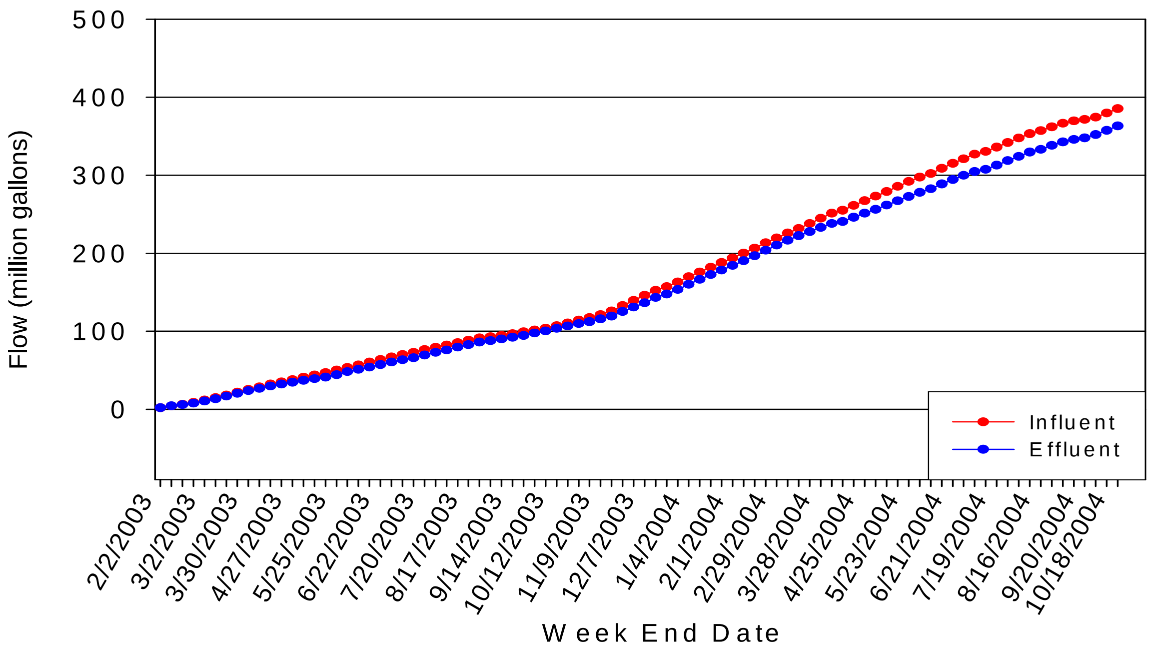


Figure 2-2. Cumulative Influent and Effluent flows for the period January 27, 2003 through October 18, 2004.

For the first quarter from 9:30 AM January 27, 2003 until 9:30 AM on May 5, 2003, the total flow into the ATS™-WHS™ Treatment Facility from L-62 was 41.27 million gallons, or an average rate of 416,869 gpd. For the second quarter, from 9:30 AM on May 5, 2003 until 9:30 AM on August 4, 2003 (excluding May 11, 2003 due to a power outage), the total flow into the ATS™-WHS™ Treatment Facility from L-62 was 40.92 million gallons, or an average rate of 449,912 gpd. For the third quarter, from 9:30 AM on August 4, 2003 until 9:30 AM on November 3, 2003 (excluding August 29-31 and September 1-2, 2003 due to shut down during herbicide application), the total flow into the ATS™-WHS™ Treatment Facility from L-62 was 35.28 million gallons, or an average rate of 410,233 gpd. Combined influent flows for these three quarters were 117.47million gallons, or an average of 425,616 gpd.

As the treatment objective was for total nutrient load removal for Quarters 4 through 6, this time period will be treated as a separate experimental phase in the operation of the S-154 facility for reporting purposes. Total measured inflow from the Parshall flume for the fourth quarter from November 3, 2003 to January 26, 2004 at 9:30 AM was 70.65 million gallons, or an average of 883,125 gpd. Fifth quarter measured inflow total from January 25 through May 31 at 9:30 AM was 110.4 million gallons, or an average 890,081 gpd. Sixth quarter measured inflow total from June 1 to October 18, 2004 was 90.3 million gallons or 759,160 gpd. Combined influent flows for these three quarters is 271.35 million gallons, or an average of 840,092 gpd. For part of Q4 and all of Q5 and Q6, small quantities of the influent flow was periodically diverted to the WHS™ North for water level maintenance –WHS™ North was taken off-line on January 1, 2004. In addition, beginning also on January 1, 2004, all settled microscreen backwash was diverted to the off-line WHS™-North as the original design for the microscreen was not suited for 1 million gallons per day of flow. Consequently, influent flows as measured, were adjusted after January 1, 2004, by deducting diverted flows, while effluent flows as measured, were adjusted by adding the microscreen backwash flows. --The influent flows, therefore, after adjustment, to the WHS™ -ATS™ system was 69.53 million gallons for Q4 (869,180 gpd), 108.59 million gallons for Q5 (875,696 gpd), and 87.98 million gallons for Q6 (739,351 gpd) equaling 266.10 million gallons of L-62 water treated by the 2-stage treatment system. Total diverted flow for the three quarters were 4.68 million gallons, or an average of 14,196 gpd. Flow diverted from the 2-stage system to WHS™-North is considered external to the dynamics of the WHS™-ATS™ system, and accordingly is not included in calculations for nutrient mass or calculation of flow-weighted concentration.

The effluent flow for the first quarter was 37.60 million gallons, or an average of 379,798 gpd. The effluent flow for the second quarter was 39.10 million gallons, or an average of 429,670 gpd. The effluent flow for the third quarter was 36.31 million gallons, or an average of 422,209 gpd. Combined effluent flows for all three quarters were 113.01 million gallons, or an average of 409,456 gpd or 96 % of influent flow.

For the fourth, fifth and sixth quarters, measured effluent flows were 65.61 million gallons, 99.62 million gallons and 85.56 million gallons, respectively. The microscreen backwash flows totaled 254,466 for the fourth quarter, 781,633 for the fifth quarter and 240,000 gallons for the sixth quarter. Therefore the reported effluent flows for the fourth quarter was 65.87 million gallons; for the fifth quarter 100.40 million gallons; and for the sixth quarter 85.53 million gallons. Daily effluent flow average was 823,415, gpd for quarter four 809,703 gpd for Q5, 718,403 for Q6. Combined effluent flow for these three quarters was 251.96 million gallons, or an average of 762,895 gpd, or 94.6% of influent flow.

The difference between the influent and effluent flows was 3.66 million gallons, or an average of 37,070 gpd, or 8.9% of influent flow for the first quarter; 1.82 million gallons, or an average of 20,242 gpd, or 4.5% of influent flow for the second quarter; and –1.03 million gallons or –11,977 gpd, or –2.9% (net effluent flow gain) of influent flow for the third quarter. For the first three quarters', 276-day monitoring period, the difference was 4.46 million gallons, or an average of 19,855 gpd, or 3.8% of influent flow.

During the fourth quarter, the difference between influent and effluent flows was 3.66 million gallons, or an average of 45,722 gpd, or 5.3% of influent flow. Fifth quarter effluent flow was 8.19 million gallons less than influent flow, or 66,071 gpd, or 7.5% less than influent flow. Sixth quarter effluent flow was 2.42 million gallons less than influent or 20,948 gpd or 2.8% of influent flow. For these three quarters, the total difference was 14.34 million gallons or an average loss of 44,396 gpd, or 5.3% of influent flow.

These differentials represent evapotranspiration (ET), seepage losses, overflow and incidental losses, minus rainfall and infiltration (Table 2-2). It is noteworthy that net losses appear to be somewhat independent of process area—recognizing that the area was reduced by more than 50 percent after January 1, 2004. This implies there are other factors other than ET are contributing significantly to the net losses, otherwise a significant reduction in net losses would have been noted when process area was reduced. These other factors likely include seepage losses and inherent fluctuations in accuracy with the flow measuring devices. In general, however, the correlation between influent and effluent is consistent, and reasonable.

Table 2-2. Total flows by quarter for January 27,2003 through October 18, 2004.

Monitoring Period	Quarter 1	Quarter 2	Quarter 3	Quarter 4	Quarter 5	Quarter 6	Total
Influent Flow (Million Gallons)	**41.27** (416,869 gpd)	**40.92** (449,912 gpd)	**35.28** (410,233 gpd)	**69.53** (869,180 gpd)	**108.59** (875,696 gpd)	**87.98** (739,351 gpd)	**383.57** (637,744 gpd)
Effluent Flow (Million Gallons)	**37.60** (379,798 gpd)	**39.10** (429,670 gpd)	**36.31** (422,209 gpd)	**65.87** (823,415 gpd)	**100.40** (809,703 gpd)	**85.56** (718,403 gpd)	**364.77** (600,941 gpd)
Loss (Gain) (Million Gallons)	**3.67** (37,070 gpd)	**1.82** (20,242 gpd)	**(1.03)** (-11,977 gpd)	**3.66** (45,772 gpd)	**8.19** (66,071 gpd)	**2.49** (20,948 gpd)	**19.4** (36,787 gpd)
% Loss	**8.89**	**4.45**	**-2.92**	**5.26**	**7.54**	**2.8%**	**4.9**

Overflow from the designed protective overflow weirs at the splitter box and the ATS™ during Q1 and Q2 was negligible. However, there was noticeable infiltration as surface inflow into the effluent flume box following a very heavy rainfall (2.1 inches in 45 minutes) on September 5, 2003 during Q3. This was due largely to rising shallow groundwater and some accumulations within contiguous stormwater ponds. This inflow event confuses the data to some extent for that particular week, as is discussed further within the text, although overall influence upon system analysis is considered negligible. A groundwater collection and pumping system was installed shortly thereafter to correct this problem.

Rainfall for the first quarter was 10.9 inches, 15.2 inches for the second quarter, and 19.7 inches for the third quarter. Considering the capture area within the process train as 5.3 acres, and assuming a 100% capture rate, the estimated rainfall contribution is 1.56 million gallons, or 17,311 gpd for the first quarter, and 2.19 million gallons, or 24,041 gpd for the second quarter, and 2.84 million gallons or 33,023 gpd for the third quarter. Consequently, ET and seepage are calculated as 54,381 gpd, or 38 gpm, or the equivalent of 0.37 inches/day for the first quarter; 44,283 gpd, or 31 gpm, or the equivalent of 0.31 inches/day for the second quarter; and 22,506 gpd, or 16 gpm, or the equivalent of 0.16 inches/day for the third quarter. For the first three quarters, total ET and seepage are calculated as 40,036 gpd, or 28 gpm, or the equivalent of 0.28 inches/day.

Rainfall was significantly less over Q4 and Q5, with 4.6 and 5.7 inches of rain received, respectively. However, 40.9 inches, of rain was received at the site during Q6. Through Q4 and Q5, the process area was reduced to 2.09 acres which equates to a rainfall contribution of 0.47 million gallons for Q4 (5,645 gpd), and 1.16 million gallons (9,143 gpd) for Q5 when considering that actual ATS™ area influenced by rainfall did not change due to design of the system. For the fourth and fifth quarters, ET and seepage, including diversions to WHS™ north are calculated as 43,727 gpd, or 30.36 gpm or the equivalent of 0.429 inches/day, and 73,331 gpd, or 50.9 gpm or 0.799 inches/day, respectively. During Q6, estimated rainfall is 4.16 million gallons (33,555 gpd). ET and seepage, including diversions to WHS™ north as well as best possible accounting for flow data lost during power outages are calculated as 4.93 million gallons (39,145 gpd) or the equivalent of 0.38 inches/day. For quarters 4 through 6, total estimated ET and seepage are calculated as 52,544 gpd or 36.5 gpm, or the equivalent of 0.52 inches/day.

Presented within Table 2-3 is a comparison of historical pan evaporation and rainfall trends with observed values for ET and Seepage. It is noteworthy that April 2003 represented the period of highest ET and seepage loss and a monthly rainfall of 5.1 inches in Q1, which is not consistent with historical data. However, lower rainfall in Q5 results in a mean April, 2004 rainfall closer to historical trends. There is no clear explanation for the high value for April 2003, although factors such as undetected overflow, excessive seepage, high ET from plant productivity, and high winds could all be contributory. Efforts were made during the first quarter to reduce overflow and seepage losses, which may provide some explanation for the reduced ET and seepage loss for the second quarter. Typically the ET and seepage losses exceeded historical pan evaporation, which is not unexpected because of the influence of the ATS™ dynamics, i.e. laminar flow over a black surface, and to some extent the high ET potential of water hyacinths. Rainfall for each of the months in the fourth and fifth quarters was lower, and air temperatures slightly higher than historical data, which may contribute to the higher ET and seepage values. Greater turbulence across the ATS™ related to high hydraulic loading rates and higher velocities may account for some of this increase, as well as the referenced diversion to WHS™-North. In addition filtered microscreen backwash was diverted to WHS™-North, and hence removed from the hydraulic cycle associated with the primary system. As noted, it is estimated that these diverted flows amounted to an average of about 30,000 gpd. These two operational procedures have some influence in the seemingly elevated difference between influent and effluent flow for quarters 4 and 5.

Table 2-3: Comparison of rainfall and evaporation with historical trend

	Historical*	**Historical***	**Historical***	**Historical***	**Project**	**Project**
Month	Average Air T (^{o}C)	Relative Humidity (%)	Pan Evaporation (inches)	Rainfall (inches)	Rainfall (inches)	ET + seepage (inches)
January, 2003	17.8	76	3.31	2.01	-	-
January, 2004	17.8	76	3.31	2.01	1.5	-29.83
February, 2003	17.8	76	3.90	1.97	0.3	4.5
February, 2004	17.8	76	3.90	1.97	1.2	-25.75
March, 2003	19.4	74	5.83	2.99	5.5	8.9
March, 2004	19.4	74	5.83	2.99	0.2	45.32
April, 2003	21.1	73	6.54	3.00	5.1	22.5
April, 2004	21.1	73	6.54	3.00	2.2	47.45
May, 2003	23.9	72	7.09	5.03	5.8	5.8
May, 2004	23.9	72	7.09	5.03	0.0	39.70
June, 2003	25.6	75	6.22	8.97	3.4	13.0
June, 2004	25.6	75	6.22	8.97	6.4	0.14

Month	Historical* Average Air T (^oC)	Historical* Relative Humidity (%)	Historical* Pan Evaporation (inches)	Historical* Rainfall (inches)	Project Rainfall (inches)	Project ET + seepage (inches)
July, 2003	26.7	78	6.26	7.87	6.0	4.6
July, 2004	26.7	78	6.26	7.87	1.9	0.14
August, 2003	27.7	78	6.02	8.01	9.4	0.65
August, 2004	27.7	78	6.02	8.01	10.3	0.05
September, 2003	27.7	79	5.81	8.39	10.2	1.59
September, 2004	27.7	79	5.81	8.39	21.7	-0.15
October, 2003	24.2	77	5.68	4.65	0.1	10.2
October, 2004	24.2	77	5.68	4.65	0.6	0.01
November, 2003	19.4	76	3.66	1.73	2.0	36.7
December, 2003	17.8	75	3.07	1.81	2.2	13.5

Source: IFAS Bulletin 840 Dec 1984 65pp** NOAA 1930-85

During July 2003 ET rates were expected to be somewhat lower than May or June, due largely to higher humidity and cloudier days. This is reflected by the data in Table 2-3. The influence of the infiltration event and heavy rains is noted in August and September 2003. ,

When the diurnal flow patterns and influent and effluent water temperature are considered, as presented within Figures 2-3 through 2-6, some support is provided regarding the role of ET as the water loss mechanism. The composite data reflects an average over the period of a specific time, with data collected every hour for water temperature and every half-hour for flow. The data recorded represents an average of inputs taken every 15 seconds over the half hour period.

Most evident is the extent of water temperature variation within the effluent, as compared to the influent, and the general increase in influent water temperature through the second quarter and into the third quarter. The variation between influent and effluent water temperature is due to the increase in ambient air temperature during these three quarters and an attendant transfer of heat primarily across the ATS™ floways. It is interesting that while influent water temperature increased notably from June through July 2003 the effluent water temperature was very similar during these two periods. This is not unexpected, because of the laminar nature of the flow across the ATS™ floways. Daily spot sampling in the field, as noted in Figure 2-13, provides evidence that the heat accumulation is occurring within the floway units, as it tends to track or exceed the air temperature. The WHS™ serves to protect the water from solar radiation through the plant coverage, as well as reducing heat losses, and therefore serves as a temperature modulator. One noticeable trend is the extent of the decrease in variation between influent and effluent temperatures during Q4 through Q6, as seen in Figure 2-6, due most likely to the cessation of recycling across the ATS™ .

Looking more closely at the comparative flow graphs as presented within Figures 2-8 through 2-12, there is noted a discernible trend for increased water loss during the daylight, higher temperature hours, from about 7:30 AM to 6:00 PM. In the early morning hours, the flows are much closer to being equal, and the differential during this time may reflect more clearly the impacts of seepage or diversion losses. The greatest differential between influent and effluent during the early morning is shown in the first quarter of 2003, providing support to the possibility of excessive overflow or seepage during these months. System maturation and corrective action appears to have reduced this differential during the second quarter. It needs to be recognized that some of the drop in effluent flow in the early morning is due to modulation of flows during harvesting of the WHS™ which commenced in mid-March, 2003. Nonetheless, the differential during the late mornings and afternoons is likely attributable largely to increased ET losses. High afternoon effluent flows in August and September 2003 are indicative of the heavy rainfall during these months.

During February 2003, this average differential between 2:00 AM and 7:00 AM was approximately 5 gpm. These values were more variable during March and April 2003 with reported mean differential values of approximately 7 gpm and 35 gpm, respectively. In May and June 2003 this differential was about 10 gpm, while in July, August and September 2003, likely due to heavy rainfall, higher humidity and some infiltration, the average effluent flow actually exceeded the average influent flow. It is also conceivable that if the ATS™ surface cools faster than the air, it could act to collect condensation (dew) in the evening. In October, with low rainfall, the losses are again noticeable in the afternoon period, due likely to increased ET over the ATS™. While the Q2 and Q3 results support the contention that seepage losses are likely to be a less important contributor to water losses than ET, this is not the case during Q4 and Q5

Between 2:00 AM and 7:00 AM during Q4, which represents November 2003 through January 2004, the mean differential between influent and effluent flow was approximately 28 gpm, with high variability between months. For November 2003, auto sampler determined effluent flows were 71 gpm less than influent, though this differential decreased significantly over the quarter with effluent flow exceeding influent flow by 19 gpm by late January 2004. This trend continued into early Q5, but in March, April and May 2004, mean effluent flows were 19, 77 and 63 gpm less than influent flow, respectively between 2:00AM and 7:00 AM. During Q4 and Q5, the impact of WHS™ harvest procedures is more pronounced and losses due to seepage and ET less so throughout the day even though mean influent vs. effluent differential from 7:30 AM to 6:00 PM is almost twice that of the previous 3 quarters. This exaggeration of influent vs. effluent during harvesting is most notably due to increased flow to the system and diversions to WHS™ north, which were conducted in the morning hours as noted previously. This analysis was not continued through Q6 as a power outage on August 25 deleted autosampler data recorded prior to this date.

The ET losses for Q1 were estimated previously at a value no greater than 0.37 inches daily. For Q2, this value is estimated at no more than 0.31 inches/daily. For Q3, this value is estimated at no more than 0.16 inches/daily. As noted, this is higher than expected pan evaporation for Q1 and Q2. It is even higher than expected ET over an active wetland area, which would reasonably be expected to be between 0.15-0.28 inches/day. However, Q3 data results in estimated ET losses that approximate pan evaporation. On a basin wide perspective, the reduced surface water exposure of the WHS™ - ATS™ (perhaps 5-10% of equivalent wetland treatment areas) would allow favorable comparison in terms of net water loss to a treatment wetland scenario.

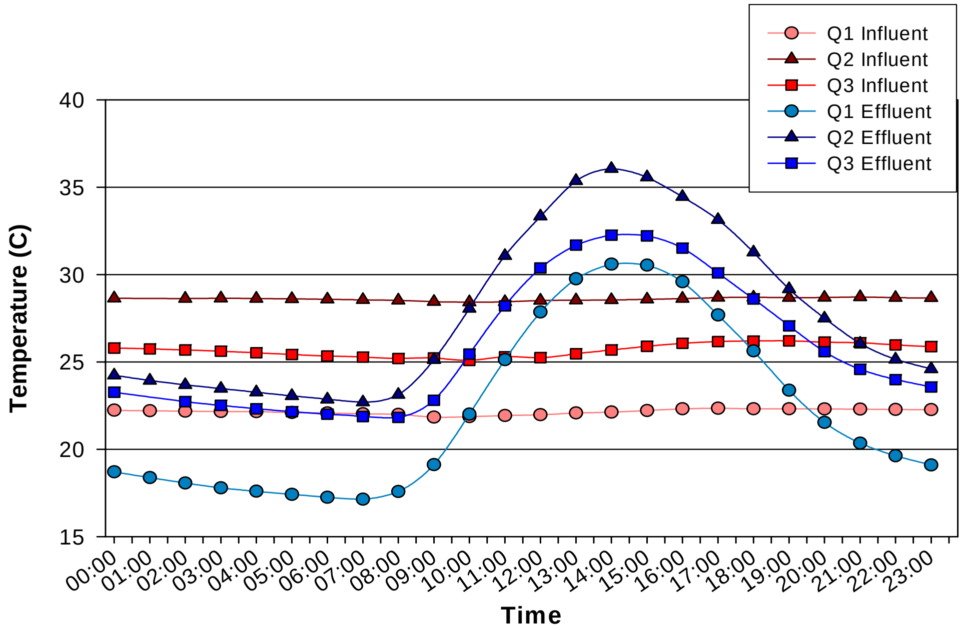


Figure 2-3: Comparative influent and effluent composite diurnal Temperature patterns for Quarters 1-3, representing the period January 27, 2003 through November 3, 2003.

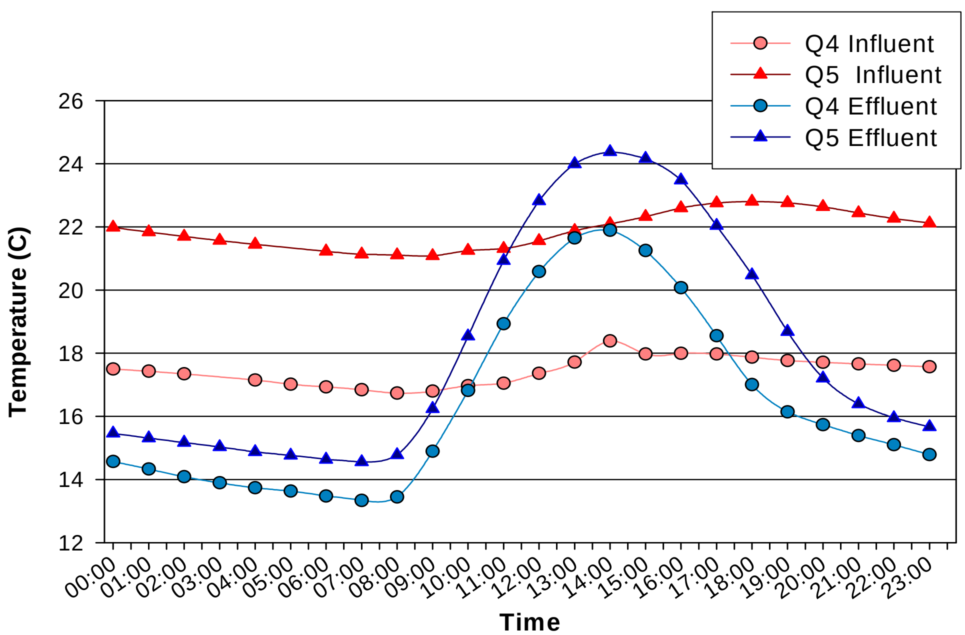


Figure 2-4: Comparative influent and effluent composite diurnal temperature patterns for Quarters 4 and 5, representing the period November 3, 2003 through May 31, 2004.

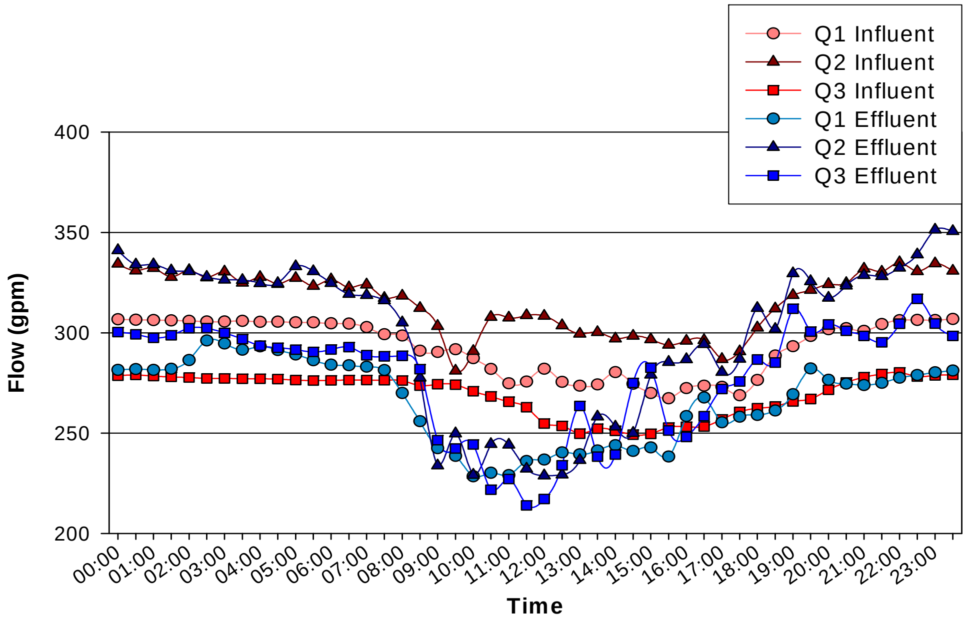


Figure 2-5: Comparative influent and effluent composite diurnal flow patterns for Quarters 1 through 3, representing the period of January 27, 2003 through November 3, 2004.

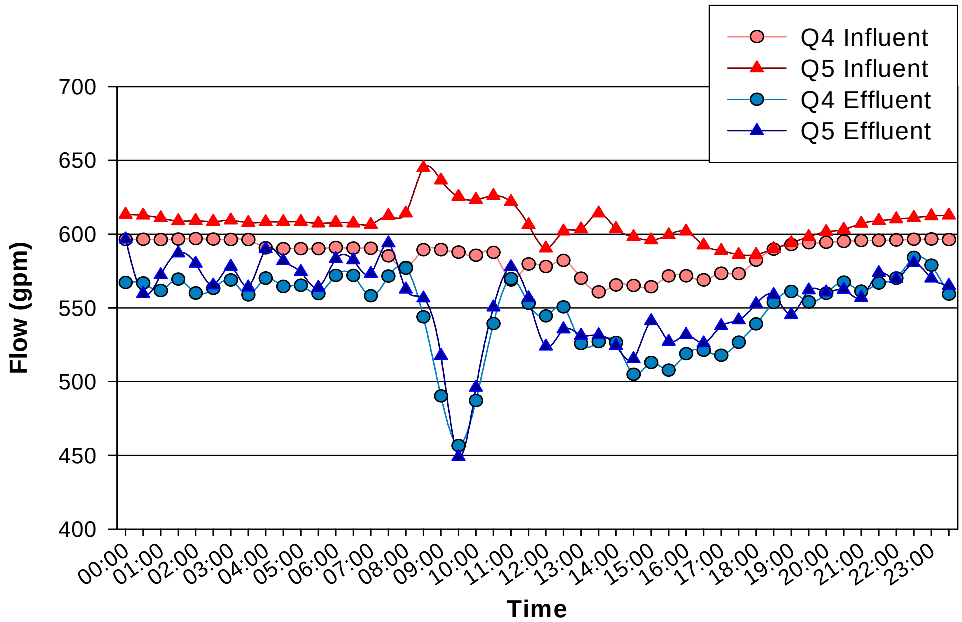


Figure 2-6: Comparative influent and effluent composite diurnal flow patterns for Quarters 4 and 5, representing the period of November 3, 2003 through May 31, 2004.

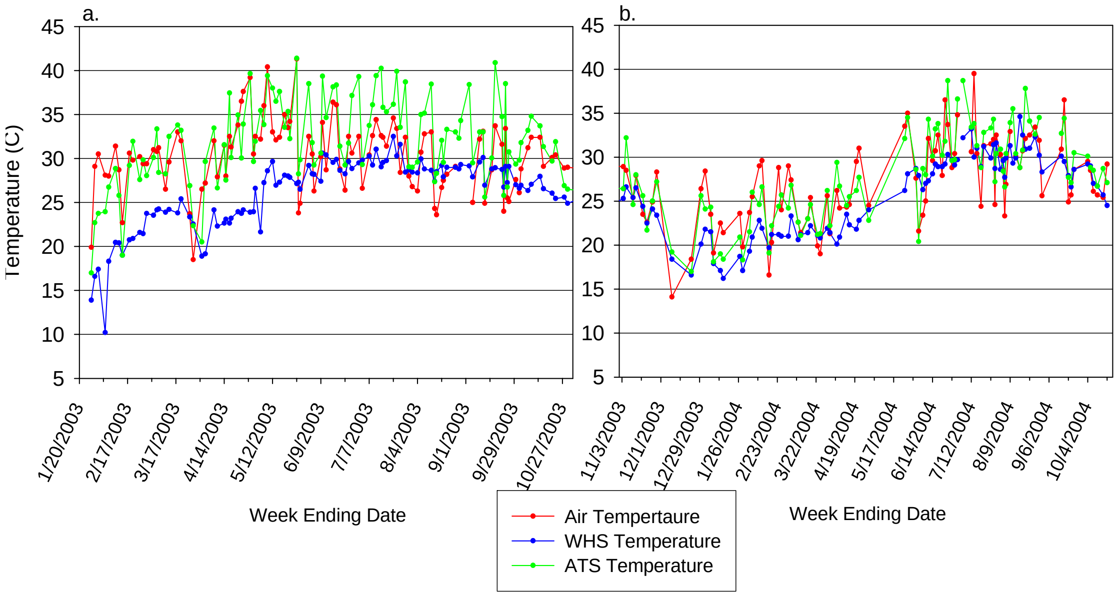


Figure 2-7: Comparative ambient air and water temperature trends as recorded for the afternoon, representing the period of record from January 27, 2003 through October 18, 2004. Figure (a.) represents Quarters 1-3, concentration reduction optimization; Figure (b.) represents Quarters 4-6, load reduction optimization.

In an effort to maintain a desired level of confidence in the two flow metering devices, calibration was done at the beginning and the end of Q1 and the end of Q2 and Q3. The calibration was performed by comparing instrument flows to weir measurements. Noted in Tables 2-4,2-5, 2-6 and 2-7 are the results of these calibrations.

These ranges of differential can be considered within the capabilities of the instrumentation. The open channel measurements used were assigned typical C values. The simultaneous readings done in February involved the diversion of influent flows down the harvest flume while the recycle pump station was shut-off, thereby by-passing both WHS™ units and allowing direct flow into the effluent Parshall flume. This method eliminated the vagaries associated with weir devices. However, this method results in extensive exposure of the ATS™ to solar radiation, which can impact the viability of the algae biomass. Therefore it was not applied during subsequent calibrations.

Table 2-4: Flow calibration data recorded at the S-154 ATS™-WHS™ Pilot Water Treatment Facility in February 2003.

Weir Description	Type	Weir Length (ft or degrees)	Height over weir (ft)	C	Calculated Flow (gpm)	Instrument Flow (gpm)	Difference
Effluent	V-notch	120 deg	0.47	0.65	325	336	3.16%
Effluent at microscreen	Rectangular	3.38	0.16	0.65	322	333	3.37%
Influent Parshall flume	Rectangular	1.97	0.23	0.65	341	336	-1.38%
Comparative Simultaneous Readings	NA	NA	NA	NA	Influent Reading 333 gpm	Effluent Reading 336 gpm	-3.00%

Table 2-5: Flow calibration data recorded at the S-154 ATS™-WHS™ Pilot Water Treatment Facility in May 2003

Weir Description	Type	Weir Length (ft or degrees)	Height over weir (ft)	C	Calculated Flow (gpm)	Instrument Flow (gpm)	Difference
Influent Parshall Flume	Rectangular	1.97	0.28	0.65	339	330	-2.79%
Effluent Run 1	V-notch	60 deg	0.31	0.65	39	39	1.09%
Effluent at Parshall flume	Rectangular	1.94	0.23	0.65	255	252	-1.24%

Table 2-6: Flow calibration data recorded at the S-154 ATS™-WHS™ Pilot Water Treatment Facility in August 2003

Weir Description	Type	Weir Length (ft or degrees)	Height over weir (ft)	C	Calculated Flow (gpm)	Instrument Flow (gpm)	Difference
Influent Parshall Flume	Rectangular	1.97	0.18	0.65	239	222	-7.81%
Effluent Run 1	V-notch	60 deg	0.55	0.65	162	167	3.15%
Effluent at Parshall flume	Rectangular	1.94	0.15	0.65	176	167	-5.35%

Table 2-7: Flow calibration data recorded at the S-154 ATS™-WHS™ Pilot Water Treatment Facility in November 2003

Weir Description	Type	Weir Length (ft or degrees)	Height over weir (ft)	C	Calculated Flow (gpm)	Instrument Flow (gpm)	Difference
Influent Par shall Flume	Rectangular	1.97	0.42	0.65	704	704	0.02%
Effluent at effluent flume	rectangular	2.6	0.31	0.65	684	670	-2.03%
Effluent overflow at Parshall flume	Rectangular	6.98	0.15	0.65	633	670	5.53%

INFLUENT AND EFFLUENT WATER QUALITY

Phosphorus

Q1 Flow-weighted water quality data for phosphorus as collected through the Sigma 900 Max refrigerated automatic samplers are noted in Table 2-8. Flow-proportionate samples were collected on a weekly basis. As noted in the Monitoring Plan as previously submitted, ortho phosphorus has a limited holding time. Therefore analysis for ortho phosphorus was performed only on the 24-hour composite sample from Day 7, or 24 hours before sample pick-up, and for the grab sample, taken at time of sample pick-up by the contract Laboratory – US Biosystems.

The ortho phosphorus values assigned to the 6-day composite sample, used for purposes of calculating flow-weighted concentrations were estimated using Equation 1.

$$OP_6 = \{[(OP_{24} + OP_g)/2] / [(TP_{24} + TP_g)/2]\}TP_6 \qquad \text{(Equation 1)}$$

Where OP_6 = ortho P concentration ppb for 6-day flow-weighted composite
OP_{24} = ortho P concentration ppb for 24-hour flow-weighted composite
OP_g = ortho P concentration for grab sample
TP_{24} = total P concentration for 24-hr flow-weighted composite
TP_g = total P concentration for grab sample
TP_6 = total P concentration for 6-day flow-weighted composite

Organic phosphorus concentrations as reported in Table 2-8 were calculated as the difference between total phosphorus and ortho phosphorus. Organic phosphorus compounds can vary significantly in terms of the associated organic complex and the method of bonding, and in their recalcitrance.

The weekly flow-weighted concentrations were calculated using Equation 2

$$TP_f = (F_6 TP_6 + F_{24} TP_{24}) / (F_6 + F_{24}) \qquad \text{(Equation 2)}$$

Where TP_f = weekly flow-weighted total phosphorus concentration
F_6 = total flow for 6-day composite period
F_{24} = total flow for 24-hour composite period

Ortho phosphorus weekly flow-weighted concentrations were also calculated using Equation 2, substituting total phosphorus (TP) with ortho phosphorus (OP). Weekly flow-weighted organic phosphorus concentrations were reported as the difference between the weekly flow-weighted total and weekly flow-weighted ortho phosphorus concentrations.

Further discussion of phosphorus dynamics is presented in the discussion under this section entitled "Analysis of Phosphorus Reduction". Weekly flow-weighted concentrations for the S-154 ATS™ - WHS™ Treatment Facility influent and effluent are presented graphically for total phosphorus, ortho phosphorus and organic phosphorus in Figures 2-8, 2-9 and 2-10, respectively.

Filtered versus Unfiltered Ortho Phosphorus

In September 2003 an audit of activities related to laboratory sample collection was conducted by the SFWMD.

It was determined during the audit that ortho phosphorus samples were not immediately filtered in the field after collection of the sample per DEP SOP table FS1000-4 Parameter #44 (40 CFR Part 136 Table II), FS 2000 Section 1.3.6. Since receipt of the audit in January 2004, the contract laboratory – U.S. Biosystems has initiated field filtering all samples to be analyzed for ortho phosphorus. To provide an estimate of the variation associated with the unfiltered samples collected prior to January

19, 2004, U.S. Biosystems has collected and analyzed paired samples via EPA Method 365.1 for both field filtered and unfiltered samples. Summary tables and charts of these data are provided in Appendix1.

For the period January 19, 2004 through March 1, 2004, forty-three paired samples (n=86) were collected from seven locations routinely sampled for ortho phosphorus at the S154 site. Paired samples included both field filtered and unfiltered samples. These samples were then analyzed for ortho phosphorus via EPA Method 365.1.

For the 43 paired samples, ortho phosphorus concentrations of unfiltered samples ranged from 310 ppb to 13 ppb with a mean of 56 ppb, while ortho phosphorus concentration of field filtered samples ranged from 310 ppb to13 ppb with a mean of 53 ppb. The mean differential between filtered and unfiltered samples was 3 ppb. Based on findings associated with the paired analysis of filtered and unfiltered samples analyzed for ortho phosphorus, it is estimated that the ortho phosphorus concentrations included in this report for the period from project start-up through January 19, 2004 that were from unfiltered samples, are estimated to reflect values that are 5.8% higher than if the samples had been field filtered. Effective January 19, 2004, all ortho phosphorus data included in conjunction with this project will reflect field filtered samples.

Table 2-8: Phosphorus flow-weighted influent and effluent water quality data for the period January 27, 2003 through October 18, 2004

Week Ending		Total Phosphorus (ppb)				Ortho Phosphorus (ppb)				Organic Phosphorus (ppb)			
		Day 1-6 Comp	Day 7 24-hr Comp	Day 7 Grab	Weekly Flow-Weighted	Day 1-6 Comp	Day 7 24-hr Comp	Day 7 Grab	Weekly Flow-Weighted	Day 1-6 Comp	Day 7 24-hr Comp	Day 7 Grab	Weekly Flow-Weighted
2/3/03	**Inf**	340	390	330	**347**	-	340	270	**294**	-	50	60	**57**
	Eff	88	80	98	**87**	-	80	60	**70**		0	38	**17**
2/10/03	**Inf**	350	380	390	**354**	-	380	390	**354**	-	0	0	**0**
	Eff	64	67	65	**64**		BDL	BDL	**BDL**		67	65	**64**
2/17/03	**Inf**	340	430	460	**351**	-	340	360	**276**	-	90	100	**75**
	Eff	88	87	93	**88**	-	BDL	BDL	**BDL**	-	87	93	**88**
2/24/03	**Inf**	440	470	380	**445**	-	260	260	**272**	-	210	120	**173**
	Eff	67	72	91	**68**	-	BDL	BDL	**BDL**	-	72	91	**68**
3/3/03	**Inf**	460	340	370	**441**	-	250	230	**299**	-	90	140	**143**
	Eff	67	66	76	**67**	-	BDL	BDL	**BDL**	-	66	76	**67**
3/10/03	**Inf**	540	460	490	**526**	-	100	180	**155**	-	360	310	**371**
	Eff	73	120	100	**81**	-	BDL	BDL	**BDL**	-	120	100	**81**
3/17/03	**Inf**	410	350	410	**418**	-	120	240	**198**	-	230	170	**220**
	Eff	87	310	120	**139**	-	10	35	**14**	-	300	80	**125**
3/24/03	**Inf**	490	560	720	**500**	-	510	570	**422**	-	50	150	**78**
	Eff	69	76	89	**70**	-	BDL	BDL	**BDL**	-	76	89	**70**
3/31/03	**Inf**	770	700	580	**760**	-	560	470	**612**	-	140	110	**148**
	Eff	79	98	146	**81**	-	50	80	**45**	-	48	66	**37**
4/7/03	**Inf**	620	560	720	**611**	-	480	600	**520**	-	80	110	**91**
	Eff	100	100	110	**100**	-	BDL	BDL	**BDL**	-	100	110	**100**

4/14/03	**Inf**	800	450	510	**749**	-	360	400	**593**	-	90	110	**156**
	Eff	92	97	93	**93**	-	BDL	BDL	**BDL**	-	97	93	**93**
4/21/03	**Inf**	580	550	680	**576**	-	310	360	**314**	-	240	320	**262**
	Eff	60	100	40	**64**	-	BDL	BDL	**BDL**	-	100	40	**64**

4/28/03	**Inf**	700	520	390	**675**	-	150	96	**182**	-	370	294	**492**
	Eff	48	60	38	**49**	-	6	11	**9**	-	54	27	**41**
5/5/03	**Inf**	730	860	950	**748**	-	630	640	**524**	-	230	310	**223**
	Eff	45	33	33	**43**	-	BDL	BDL	**BDL**	-	33	33	**43**
5/12/03	**Inf**	770	*	840	**770**	-	*	600	**550**	-	*	240	**220**
	Eff	33	*	100	**33**	-	*	0	**0**		*	100	**33**
5/19/03	**Inf**	820	410	490	**756**	-	410	440	**714**	-	0	50	**42**
	Eff	58	40	50	**55**		BDL	BDL	**BDL**		40	50	**55**
5/26/03	**Inf**	340	220	300	**324**	-	170	220	**243**	-	50	80	**81**
	Eff	37	39	41	**37**	-	BDL	BDL	**BDL**	-	39	41	**37**
6//2/03	**Inf**	250	330	370	**262**	-	240	240	**180**	-	90	130	**82**
	Eff	39	33	49	**38**	-	BDL	BDL	**BDL**	-	33	49	**38**
6/9/03	**Inf**	340	420	460	**351**	-	380	370	**299**	-	40	90	**52**
	Eff	36	36	42	**36**	-	BDL	BDL	**BDL**	-	36	42	**36**
6/16/03	**Inf**	430	460	490	**435**	-	400	400	**366**	-	60	90	**69**
	Eff	30	30	46	**30**	-	BDL	BDL	**BDL**	-	30	46	**30**
6/23/03	**Inf**	360	290	210	**350**	-	200	150	**245**	-	90	60	**105**
	Eff	52	56	94	**53**	-	BDL	BDL	**BDL**	-	56	94	**53**
6/30/03	**Inf**	350	450	550	**366**	-	320	400	**263**	-	130	110	**102**
	Eff	53	45	65	**52**	-	BDL	BDL	**BDL**	-	45	65	**52**
7/7/03	**Inf**	580	600	670	**582**	-	420	460	**403**	-	180	210	**179**
	Eff	85	100	140	**87**	-	BDL	BDL	**BDL**	-	100	140	**87**
7/14/03	**Inf**	790	530	680	**751**	-	400	500	**559**	-	130	180	**192**
	Eff	110	180	240	**120**	-	120	150	**77**	-	60	90	**43**
7/21/03	**Inf**	360	440	490	**375**	-	260	310	**230**	-	180	180	**145**
	Eff	190	240	200	**200**	-	96	120	**98**	-	144	80	**102**
7/28/03	**Inf**	270	170	170	**255**	-	100	100	**150**	-	70	70	**105**
	Eff	150	83	110	**142**	-	BDL	60	**44**	-	83	50	**98**
8/4/03	**Inf**	190	220	210	**194**	-	73	86	**72**	-	155	124	**122**
	Eff	75	65	90	**74**	-	BDL	37	**18**	-	65	53	**56**

BDL = Below Detectable Limits. The detection limit for ortho phosphorus is 4 ppb.

Table 2-8: Continued

Week Ending		Total Phosphorus (ppb)				Ortho Phosphorus (ppb)				Organic Phosphorus (ppb)			
		Day 1-6 Comp	Day 7 24-hr Comp	Day 7 Grab	Weekly Flow-Weighted	Day 1-6 Comp	Day 7 24-hr Comp	Day 7 Grab	Weekly Flow-Weighted	Day 1-6 Comp	Day 7 24-hr Comp	Day 7 Grab	Weekly Flow-Weighted
8/11/03	**Inf**	300	250	280	**293**	-	180	200	**210**	-	80	240	**83**
	Eff	63	44	77	**61**	-	7	39	**23**		31	100	**38**
8/18/03	**Inf**	410	520	480	**425**	-	400	400	**344**	-	120	80	**81**
	Eff	53	49	61	**52**		21	34	**26**		28	27	**26**
8/25/03	**Inf**	640	530	590	**628**	-	410	460	**488**	-	120	130	**140**
	Eff	88	130	140	**94**	-	10	70	**28**	-	110	70	**66**
9/1/03	**Inf**	670	-	-	**670**	-	-	-	**-**	-	-	-	**-**
	Eff	67	-	-	**67**	-	-	-	**-**	-	-	-	**-**
9/8/03	**Inf**	690	-	600	**690**	-	480	-	**543**	-	-	120	**147**
	Eff	155	-	160	**155**	-	120	-	**116**	-	-	40	**39**
9/15/03	**Inf**	560	440	430	**544**	-	320	330	**406**	-	120	100	**138**
	Eff	100	150	160	**109**	-	35	110	**51**	-	115	50	**58**
9/22/03	**Inf**	350	310	330	**344**	-	230	290	**240**	-	80	40	**105**
	Eff	68	81	110	**70**	-	32	110	**45**	-	49	0	**25**
9/29/03	**Inf**	330	270	310	**320**	-	190	230	**232**	-	80	80	**88**
	Eff	77	110	130	**83**	-	25	93	**41**	-	85	37	**42**
10/6/03	**Inf**	400	410	470	**401**	-	350	430	**356**	-	60	40	**45**
	Eff	61	61	100	**61**	-	12	64	**29**	-	49	36	**32**
10/13/03	**Inf**	540	420	470	**524**	-	380	380	**447**	-	40	90	**77**
	Eff	69	86	180	**71**	-	29	130	**43**	-	40	60	**28**
10/20/03	**Inf**	410	390	380	**407**	-	320	320	**334**	-	70	60	**73**
	Eff	89	90	130	**89**	-	43	92	**55**	-	47	38	**34**
10/27/03	**Inf**	350	320	330	**346**	-	250	260	**271**	-	70	70	**75**
	Eff	68	74	120	**69**	-	17	83	**35**	-	56	37	**34**
11/3/03	**Inf**	300	330	280	**304**	-	250	190	**220**	-	80	90	**84**
	Eff	88	84	91	**87**	-	11	45	**28**	-	73	46	**59**
11/10/03	**Inf**	280	no sample	300	**280**	-	no sample	220	**205**	-	no sample	80	**75**
	Eff	no sample	120	240	**120**	-	no sample	120	**60**	-	no sample	120	**60**
11/17/03	**Inf**	290	310	310	**294**	-	250	250	**237**	-	60	60	**57**
	Eff	70	86	150	**82**	-	13	110	**46**	-	57	40	**36**
11/24/03	**Inf**	230	180	190	**223**	-	110	110	**133**	-	70	80	**90**
	Eff	68	80	120	**95**	-	29	77	**54**	-	39	43	**42**
12/1/03	**Inf**	170	160	180	**109**	-	78	71	**48**	-	82	109	**61**
	Eff	71	76	96	**75**	-	no sample	50	**32**	-	no sample	46	**44**

Week Ending		Total Phosphorus (ppb)				Ortho Phosphorus (ppb)				Organic Phosphorus (ppb)			
		Day 1-6 Comp	Day 7 24-hr Comp	Day 7 Grab	Weekly Flow-Weighted	Day 1-6 Comp	Day 7 24-hr Comp	Day 7 Grab	Weekly Flow-Weighted	Day 1-6 Comp	Day 7 24-hr Comp	Day 7 Grab	Weekly Flow-Weighted
12/8/03	**Inf**	130	100	110	**126**	-	53	54	**66**	-	47	56	**59**
	Eff	57	51	58	**52**	-	16	38	**24**	-	41	20	**27**
12/15/03	**Inf**	110	110	100	**110**	-	no sample	43	**43**	-	no sample	57	**67**
	Eff	66	60	57	**61**	-	13	36	**24**	-	53	21	**37**
12/22/03	**Inf**	100	110	no sample	**102**	-	62	no sample	**56**	-	48	no sample	**46**
	Eff	55	65	no sample	**63**	-	27	no sample	**31**	-	28	no sample	**32**
12/29/03	**Inf**	140	140	130	**140**	-	89	93	**94**	-	51	37	**46**
	Eff	49	53	73	**52**	-	23	39	**27**	-	26	34	**26**
1/5/2004	**Inf**	140	120	130	**137**	-	76	81	**86**	-	44	49	**51**
	Eff	56	74	79	**72**	-	22	29	**27**	-	34	50	**44**
1/12/04	**Inf**	140	140	130	**140**	-	62	62	**64**	-	78	68	**76**
	Eff	56	80	77	**77**	-	25	48	**42**	-	31	29	**35**
1/19/04	**Inf**	150	150	120	**150**	-	no sample	61	**64**	-	no sample	59	**86**
	Eff	56	94	70	**89**	-	21	39	**43**	-	35	31	**46**
1/26/04	**Inf**	110	130	110	**113**	-	60	53	**53**	-	70	57	**60**
	Eff	71	77	65	**76**	-	19	37	**31**	-	52	28	**45**
2/2/2004	**Inf**	140	140	120	**138**	-	55	54	**60**	-	85	66	**78**
	Eff	70	86	76	**84**	-	13	36	**28**	-	57	40	**56**
2/9/04	**Inf**	110	100	110	**137**	-	42	41	**59**	-	58	69	**78**
	Eff	62	54	64	**84**	-	21	42	**28**	-	41	22	**56**
2/16/04	**Inf**	110	150	160	**116**	-	54	54	**29**	-	96	106	**86**
	Eff	75	76	79	**76**	-	19	44	**31**	-	56	35	**45**
2/23/04	**Inf**	130	110	120	**127**	-	40	34	**36**	-	70	86	**91**
	Eff	62	70	65	**69**	-	17	38	**27**	-	45	27	**42**
3/1/04	**Inf**	140	200	230	**148**	-	140	180	**110**	-	60	50	**38**
	Eff	56	67	61	**66**	-	13	28	**34**	-	43	33	**32**
3/8/04	**Inf**	400	470	500	**407**	-	380	380	**323**	-	90	120	**84**
	Eff	53	110	170	**103**	-	18	120	**72**	-	35	50	**32**
3/15/04	**Inf**	400	460	450	**410**	-	370	360	**325**	-	90	90	**86**
	Eff	120	170	180	**164**	-	80	160	**131**	-	40	20	**33**
3/22/04	**Inf**	600	570	520	**596**	-	400	370	**399**	-	170	150	**197**
	Eff	240	230	260	**231**	-	170	220	**176**	-	70	40	**56**
3/29/04	**Inf**	420	390	360	**416**	-	260	240	**266**	-	130	120	**150**
	Eff	170	200	210	**198**	-	120	160	**137**	-	50	50	**61**
4/5/04	**Inf**	290	290	330	**290**	-	200	180	**159**	-	90	150	**131**

Week Ending		Total Phosphorus (ppb)				Ortho Phosphorus (ppb)				Organic Phosphorus (ppb)			
		Day 1-6 Comp	Day 7 24-hr Comp	Day 7 Grab	Weekly Flow-Weighted	Day 1-6 Comp	Day 7 24-hr Comp	Day 7 Grab	Weekly Flow-Weighted	Day 1-6 Comp	Day 7 24-hr Comp	Day 7 Grab	Weekly Flow-Weighted
	Eff	140	160	140	**157**	-	110	110	**118**	-	30	30	**39**
4/12/04	Inf	340	320	330	**335**	-	75	83	**76**	-	245	247	**259**
	Eff	180	140	140	**151**	-	29	63	**53**	-	151	77	**98**
4/19/04	Inf	270	330	250	**279**	-	120	85	**78**	-	210	165	**201**
	Eff	110	120	120	**118**	-	32	60	**44**	-	78	60	**75**
4/26/04	Inf	220	200	180	**218**	-	41	28	**49**	-	159	152	**169**
	Eff	87	100	87	**98**	-	18	28	**28**	-	69	59	**71**
5/3/04	Inf	270	260	250	**227**	-	57	62	**46**	-	203	188	**181**
	Eff	120	96	11	**99**	-	23	37	**29**	-	97	73	**70**
5/10/04	Inf	180	210	200	**184**	-	46	50	**40**	-	164	150	**145**
	Eff	76	110	82	**106**	-	13	36	**31**	-	63	46	**74**
5/17/04	Inf	210	220	210	**211**	-	38	45	**41**	-	182	165	**170**
	Eff	83	150	79	**141**	-	10	22	**37**	-	73	57	**104**
5/24/04	Inf	240	240	240	**240**	-	35	38	**34**	-	205	202	**207**
	Eff	89	91	82	**91**	-	12	23	**20**	-	77	59	**71**
5/31/04	Inf	320	220	230	**306**	-	39	36	**51**	-	181	36	**255**
	Eff	85	87	80	**87**	-	9.5	24	**18**	-	76	56	**68**
6/7/04	Inf	240	200	140	**232**	-	23	19	**31**		177	121	**201**
	Eff	130	75	67	**120**	-	14	23	**27**		61	44	**93**
6/14/04	Inf	170	140	99	**166**	-	16	15	**21**		124	84	**145**
	Eff	63	45	43	**61**	-	9	12	**14**		36	31	**46**
6/21/04	Inf	150	130	100	**147**	-	17	18	**22**		113	82	**125**
	Eff	59	76	53	**62**	-	10	8	**9**		76	46	**53**
6/28/04	Inf	110	110	110	**110**	-	12	12	**12**		98	98	**98**
	Eff	48	32	24	**46**	-	6	3	**7**		26	21	**39**
7/5/04	Inf	77	110	44	**83**	-	13	6	**10**		97	38	**72**
	Eff	39	40	60	**39**	-	8	8	**7**		40	52	**32**
7/12/04	Inf	100	92	77	**98**	-	13	10	**13**		79	68	**85**
	Eff	39	37	33	**38**	-	3	4	**3**		34	29	**35**
7/19/04	Inf	40	100	81	**87**	-	3	BDL	**2**		97	0	**85**
	Eff	85	36	33	**39**	-	BDL	BDL	**0**		36	29	**39**
7/26/04	Inf	87	98	90	**89**	-	8	9	**8**		90	82	**81**
	Eff	40	41	43	**40**	-	5	4	**4**		36	39	**36**
8/2/04	Inf	80	74	79	**79**	-	9	7	**8**		65	72	**71**
	Eff	42	46	55	**43**	-	4	6	**4**		46	49	**38**
8/9/04	Inf	71	65	79	**70**	-	10	6	**8**		55	73	**62**
	Eff	58	51	48	**56**	-		5	**3**		51	43	**53**
	Inf	93	81	110	**91**	-	17	29	**22**		64	81	**69**

Week Ending		Total Phosphorus (ppb)				Ortho Phosphorus (ppb)				Organic Phosphorus (ppb)			
		Day 1-6 Comp	Day 7 24-hr Comp	Day 7 Grab	Weekly Flow-Weighted	Day 1-6 Comp	Day 7 24-hr Comp	Day 7 Grab	Weekly Flow-Weighted	Day 1-6 Comp	Day 7 24-hr Comp	Day 7 Grab	Weekly Flow-Weighted
8/16/04	Eff	60	44	47	**56**	-	BDL	4	**2**		44	43	**54**
	Inf	390	630	790	**426**	-	460	550	**303**		170	240	**123**
8/23/04	Eff	800	170	300	**91**	-	70	210	**55**		170	90	**37**
	Inf	790	1100	1100	**845**	-	910	730	**630**		190	370	**215**
8/30/04	Eff	450	870	600	**527**	-	300	490	**283**		870	110	**244**
	Inf		640		**640**	-							
9/9/04	Eff		585		**585**	-							
	Inf	1000	980	850	**992**	-	750	720	**797**		230	130	**195**
9/20/04	Eff	600	670	460	**625**	-	530	380	**503**		670	80	**122**
	Inf	720			**543**	-							
9/27/04	Eff	620			**509**	-							
	Inf	860	1100	1000	**890**	-		1000	**848**		1100		**42**
10/11/04	Eff	1100	960	1000	**1081**	-	870	960	**1010**		960	40	**72**
	Inf	1100	980	980	**1084**	-		940	**1045**		980	40	**39**
10/18/04	Eff	960	970	1000	**961**	-	920	970	**922**		970	30	**39**

BDL = Below Detectable Limits. The detection limit for ortho phosphorus is 4 ppb.

Weekly flow-weighted loads for the S-154 WHS™ - ATS™ Treatment Facility influent and effluent are presented graphically for total phosphorus, ortho phosphorus and organic phosphorus in Figures 2-11, 2-12 and 2-13, respectively. In addition to the phosphorus analyses as delineated within the monitoring plan, grab samples were taken from the WHS™ effluent, and from both the North and South ATS™ effluents (pre-microscreen). These results are noted in Table 2-9.

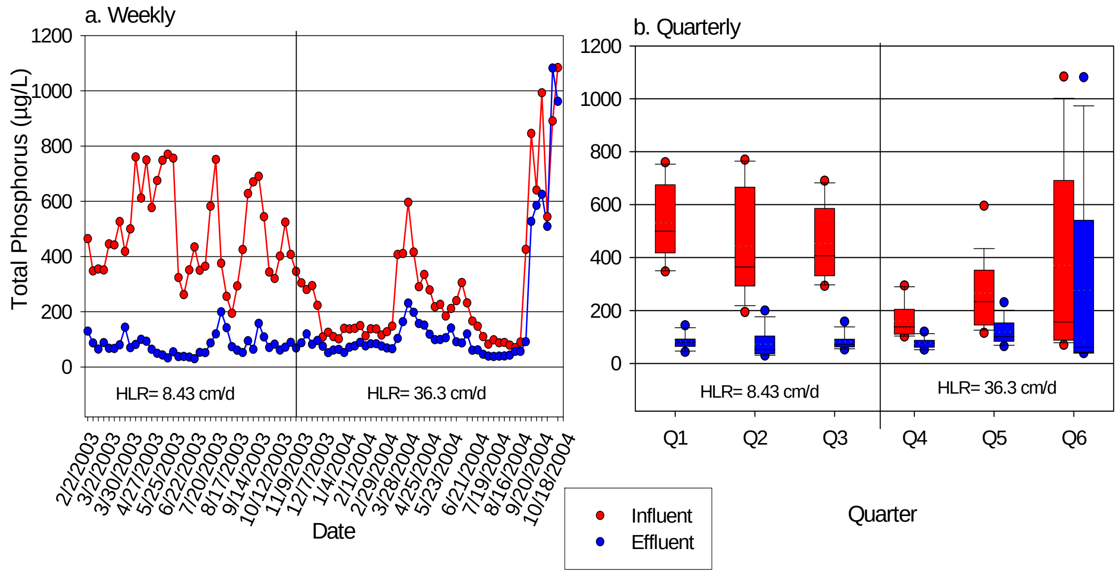


Figure 2-8: Influent and effluent weekly flow-weighted total phosphorus concentrations for the period January 27, 2003 through October 18, 2004.

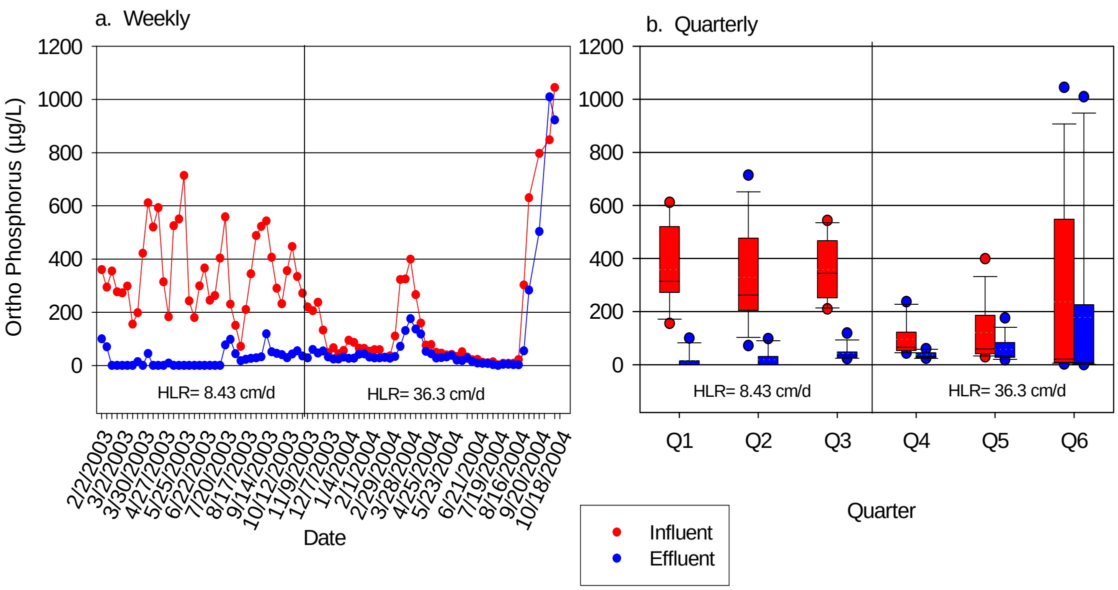


Figure 2-9: Influent and effluent weekly flow-weighted ortho phosphorus concentrations for the period January 27, 2003 through October 18, 2004

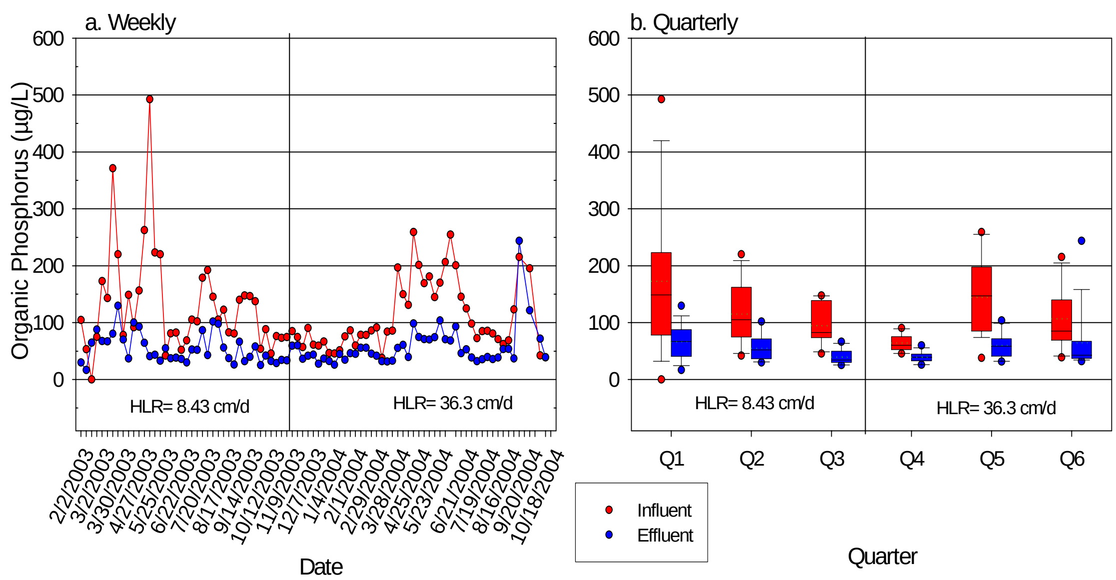


Figure 2-10: Influent and effluent weekly flow-weighted organic phosphorus concentrations for the period January 27, 2003 through October 18, 2004.

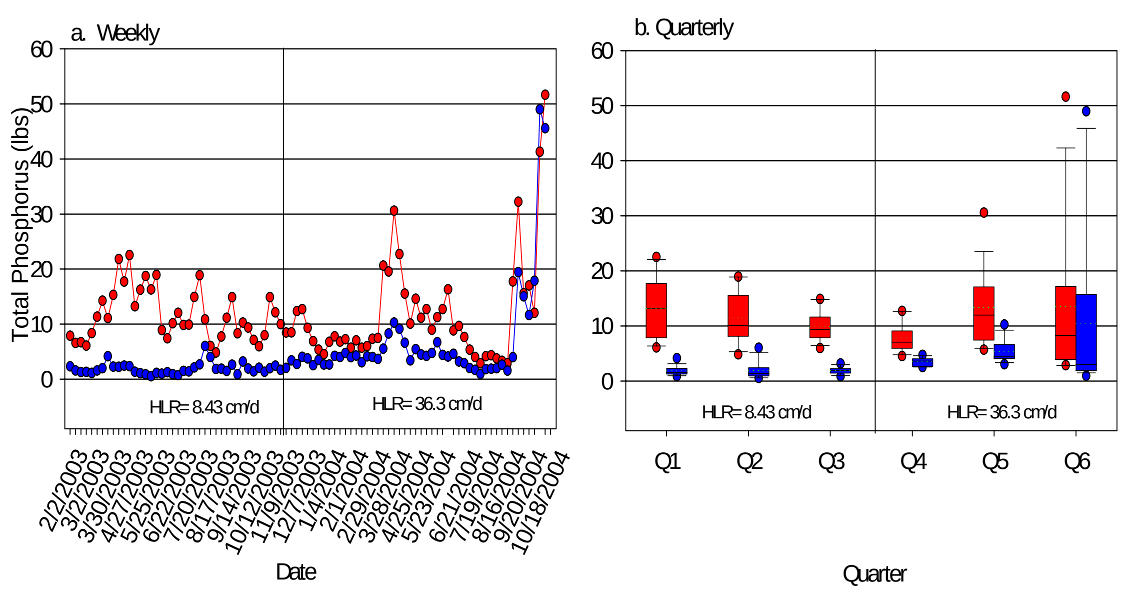


Figure 2-11: Influent and effluent flow-weighted total phosphorus loads for the period January 27, 2003 through October 18, 2004.

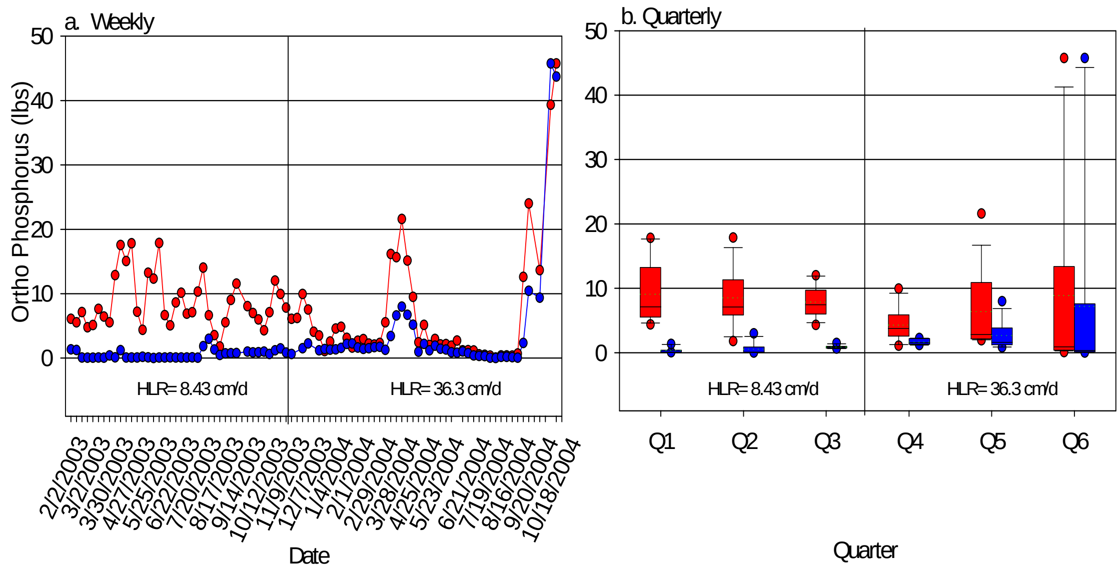


Figure 2-12: Influent and effluent weekly flow-weighted ortho phosphorus loads for the period January 27, 2003 through October 18, 2004.

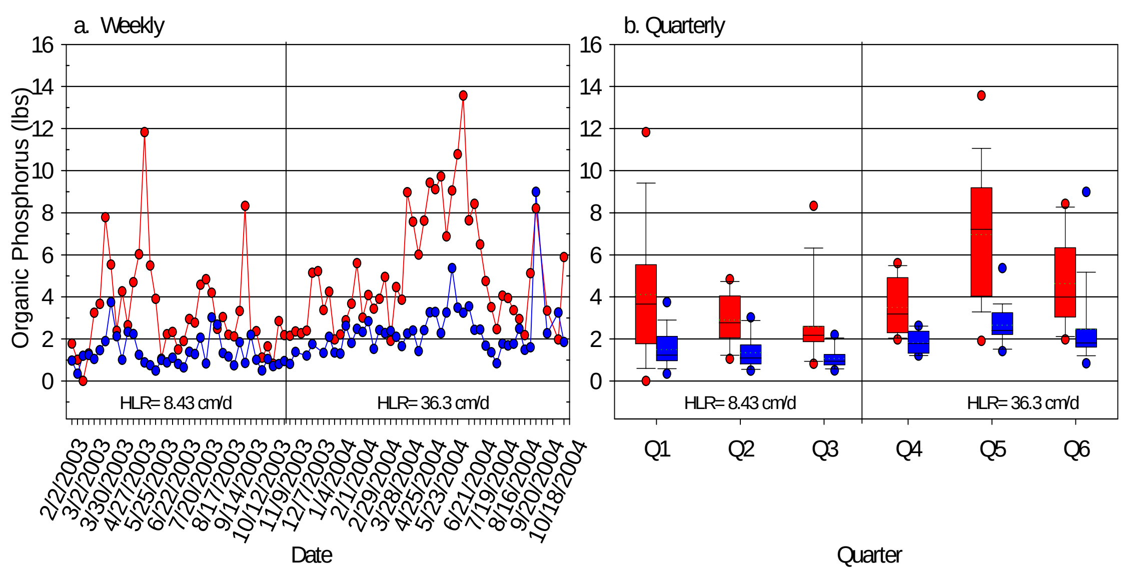


Figure 2-13: Influent and effluent weekly flow-weighted organic phosphorus loads for the period January 27, 2003 through October 18, 2004.

Table 2-9: WHS™ and ATS™ effluent phosphorus data collected as grab samples for the period February 3, 2003 through October 18, 2004.

Week Ending	2/3	2/10	2/17	2/24	3/ 3	3/10	3/17	3/24	3/31	4/7	4/14	4/21	4/28	5/5
WHS™ Effluent TP (ppb)	110	68	120	100	86	150	130	180	210	210	150	53	66	78
WHS™ Effluent Ortho-P (ppb)	-	-	-	-	-	BDL	33	140	150	180	120	BDL	28	BDL
WHS™ Effluent Org-P (ppb)	-	-	-	-	-	150	97	40	70	30	30	53	38	78
ATS™ North Effluent TP (ppb)	130	99	130	120	140	180	130	96	150	160		57		37
ATS™ South Effluent TP (ppb)	110	99	140	120	120	210	170	100	160	150		52		33

Week Ending	5/12	5/19	5/26	6/2	6/9	6/16	6/23	6/30	7/7	7/14	7/21	7/28	8/4
WHS™ Effluent TP (ppb)	110	180	160	150	170	220	220	200	330	500	320	220	190
WHS™ Effluent Ortho-P (ppb)	0	170	140	86	160	180	170	150	220	350	206	150	110
WHS™ Effluent Org-P (ppb)	110	10	20	64	10	40	50	50	110	150	114	75	80
ATS™ North Effluent TP (ppb)	67	58	51	55	49	50	100	66	140	240	210	120	85
ATS™ South Effluent TP (ppb)	57	130	54	60	53	58	99	73	150	250	220	120	85

Table 2-9: Continued

Week Ending	8/11	8/18	8/25	9/1	9/8	9/15	9/22	9/29	10/6	10/13	10/20	10/27	11/3
WHS™ Effluent TP (ppb)	190	180	280	240	260	280	160	200	180	250	240	170	160
WHS™ Effluent Ortho-P (ppb)	94	170	200	170	200	180	130	130	130	170	170	120	92
WHS™ Effluent Org-P (ppb)	96	10	80	70	60	100	30	70	50	80	70	50	68
ATS™ North Effluent TP (ppb)	84	75	150	84	160	210	150	130	ND	210	170	140	99
ATS™ South Effluent TP (ppb)	84	70	150	100	180	170	160	140	ND	230	160	130	100

← 2003 2004 →

Week Ending*	11/10	11/17	11/24	12/1	12/8	12/15	12/22	12/29	1/5	1/12	1/19	1/26	2/2
WHS™ Effluent TP (ppb)	160	210	160	130	95	82	80	96	110	110	94	90	100
WHS™ Effluent Ortho-P (ppb)	130	160	74	59	50	38	33	54	39	47	50	48	42
WHS™ Effluent Org-P (ppb)	30	50	86	71	45	44	47	42	71	63	44	42	58
ATS™ South Effluent TP (ppb)	210	150	140	95	56	68	59	86	95	96	73	71	81

Table 2-9: Continued

Week Ending*	2/9	2/16	2/23	3/1	3/8	3/15	3/22	3/29	4/5	4/12	4/19	4/26	5/3
WHS™ Effluent TP (ppb)	86	120	120	110	220	260	340	230	210	190	140	100	120
WHS™ Effluent Ortho-P (ppb)	33	33	32	59	140	190	240	150	120	42	43	20	29
WHS™ Effluent Org-P (ppb)	53	87	88	51	80	70	100	80	90	148	97	80	91
ATS™ South Effluent TP (ppb)	69	82	73	54	180	200	250	230	220	110	110	78	120

Week Ending*	5/10	5/17	5/24	5/31	6/7	6/14	6/21	6/28	7/5	7/12	7/19
WHS™ Effluent TP (ppb)	100	100	100	110	71	51	63	30	40	47	43
WHS™ Effluent Ortho-P (ppb)	22	23	22	21	16	12	11	9	9	7	5
WHS™ Effluent Org-P (ppb)	78	77	78	89	55	39	52	22	31	40	38
ATS™ South Effluent TP (ppb)	90	80	110	85	120	61	62	46	39	38	39

Week Ending*	7/26	8/2	8/9	8/16	8/23	8/30	9/9	9/20	9/27	10/11	10/18
WHS™ Effluent TP (ppb)	41	80	58	53	340	660		810			1000
WHS™ Effluent Ortho-P (ppb)	8	8	10	8	240	540		670			990
WHS™ Effluent Org-P (ppb)	33	72	48	45	100	120		140			10
ATS™ South Effluent TP (ppb)	40	43	56	56	91	527	585	625	509	1081	961

Nitrogen

The weekly flow-weighted water quality data for nitrogen as collected through the refrigerated flow-proportionate automatic samplers are noted in Table 2-10. Nitrite-nitrogen was sampled on the 24-hour, Day 7 composite. It is not shown in the table as all values were below detectable limits (BDL). The total nitrogen is calculated as the sum of Total Kjeldahl nitrogen or TKN (ammonia plus total organic nitrogen or TON) and nitrate plus nitrite nitrogen. The weekly total nitrogen concentration reported in Table 2-10 is a flow-weighted value calculated per Equation 2.

Weekly flow-weighted concentrations for influent and effluent are presented graphically for total nitrogen in Figure 2-14. Loads are noted in Figure 2-15. The "Adjusted Influent Total Nitrogen" concentration shown within these graphs includes supplemented nitrogen, which is not included in Table 2-10. The nitrogen supplementation program is discussed under this section entitled "Analysis of Nitrogen Reduction". All influent samples were taken prior to nitrogen supplementation, and reflect the source water quality from the L-62 Impoundment. Some nitrogen sampling was done on grab samples from the WHS™. The results of these grab samples are noted in Table 2-11.

Noted in Figure 2-14 is a spike in influent nitrogen concentration for the week of September 1, 2003 through September 8, 2003. Also, there were several instances during late December 2003, through early February 2004 when the effluent TN was higher than the influent TN concentrations. This was corrected by reducing supplemented nitrogen. Overall effluent TN concentrations average well below the influent TN concentration over the period of record.

Table 2-10: Nitrogen flow-weighted influent and effluent water quality data for the period January 27, 2003 through October 18, 2004.

Week Ending		Nitrate-N (mg/l)		Total Organic N (mg/l)		Ammonia N (mg/l)		TKN (mg/l)		Total Nitrogen (mg/l)
		Day 1-6 Comp	Day 7 24-hr Comp	Day 1-6 Comp	Day 7 24-hr Comp	Day 1-6 Comp	Day 7 24-hr Comp	Day 1-6 Comp	Day 7 24-hr Comp	Weekly Flow-Weighted
2/3/03	**Inf**	0.02	BDL	1.62	1.68	0.07	0.02	1.69	1.70	1.73
	Eff	0.02	BDL	1.69	1.59	0.11	0.01	1.80	1.60	1.68
2/10/03	**Inf**	0.03	BDL	1.69	1.70	0.11	BDL	1.80	1,70	1.81
	Eff	0.02	BDL	1.61	1.60	0.09	BDL	1.70	1.60	1.69
2/17/03	**Inf**	0.03	BDL	2.62	1.70	0.08	BDL	2.70	1.70	2.64
	Eff	0.03	BDL	1.90	1.80	0.10	BDL	2.00	1.80	1.71
2/24/03	**Inf**	BDL	BDL	2.38	1.79	0.06	BDL	2.44	1.80	2.50
	Eff	BDL	BDL	2.44	1.70	0.10	BDL	2.54	1.70	1.79
3/3/03	**Inf**	BDL	0.06	1.80	1.42	0.10	0.18	1.90	1.60	1.88
	Eff	BDL	BDL	1.72	1.38	0.08	0.12	1.80	1.50	1.63
3/10/03	**Inf**	BDL	0.06	1.71	1.27	0.19	0.33	1.90	1.60	1.85
	Eff	BDL	BDL	1.43	1.60	0.17	0.36	1.60	2.00	1.71
3/17/03	**Inf**	BDL	0.12	2.72	2.04	0.18	0.26	2.90	2.30	2.85
	Eff	0.10	BDL	2.21	3.34	0.19	0.06	2.40	3.40	2.65

3/24/03	**Inf**	BDL	0.02	0.91	0.66	0.11	0.16	1.00	0.82	1.11
	Eff	BDL	BDL	1.71	1.21	0.09	0.09	1.80	1.30	0.94
3/31/03	**Inf**	BDL	BDL	2.07	1.49	0.23	0.31	2.30	1.80	2.33
	Eff	BDL	BDL	2.34	1.86	0.16	0.04	2.50	1.90	1.83
4/7/03	**Inf**	BDL	BDL	2.50	0.24	0.17	0.36	2.67	0.60	2.60
	Eff	BDL	BDL	1.83	1.94	0.17	0.16	2.00	2.10	0.82
4/14/03	**Inf**	BDL	BDL	2.36	2.11	0.14	0.19	2.50	2.30	2.40
	Eff	BDL	BDL	1.66	1.83	0.40	0.08	2.06	1.91	2.25
4/21/03	**Inf**	BDL	BDL	2.10	1.88	0.20	0.22	2.30	2.10	2.36
	Eff	BDL	BDL	2.12	1.73	0.18	0.27	2.30	2.10	2.09
4/28/03	**Inf**	BDL	0.03	1.89	1.41	0.41	0.24	2.30	1.80	2.22
	Eff	BDL	0.03	2.12	1.73	0.29	0.09	1.70	1.40	1.78
5/5/03	**Inf**	BDL	0.14	1.68	1.28	0.42	0.52	2.10	1.80	2.07
	Eff	BDL	0.03	1.49	1.22	0.41	0.18	1.90	1.40	1.87
5/12/03	**Inf**	0.06	-	1.46	-	0.64	-	2.10	-	2.16
	Eff	BDL	-	1.32	-	0.48	-	1.80	-	1.80
5/19/03	**Inf**	BDL	BDL	2.36	1.51	0.64	0.49	3.00	2.00	2.81
	Eff	BDL	BDL	1.51	1.39	0.29	0.11	1.80	1.50	1.91
5/26/03	**Inf**	BDL	BDL	1.85	1.31	0.25	0.19	2.10	1.50	2.02
	Eff	BDL	0.48	1.31	1.01	0.19	0.09	1.50	1.10	1.51
6/2/03	**Inf**	BDL	BDL	1.90	2.00	0.30	0.40	2.20	2.50	2.25
	Eff	BDL	BDL	1.46	1.40	0.24	0.10	1.70	1.50	1.68
6/9/03	**Inf**	BDL	BDL	1.32	1.55	0.55	2.10	1.90	2.10	1.93
	Eff	BDL	BDL	1.04	1.11	0.09	1.20	1.30	1.21	1.29
6/16/03	**Inf**	BDL	BDL	1.43	1.60	0.57	0.40	2.00	2.00	2.00
	Eff	BDL	BDL	1.24	1.04	0.26	0.06	1.50	1.10	1.52
6/23/03	**Inf**	BDL	0.08	1.81	1.62	0.29	0.36	2.10	1.40	2.04
	Eff	BDL	BDL	1.24	1.27	0.08	0.03	1.70	1.30	1.46
6/30/03	**Inf**	BDL	0.13	1.76	1.81	0.24	0.19	2.00	1.76	2.00
	Eff	BDL	BDL	1.26	1.40	0.14	0	1.40	1.26	1.51
7/7/03	**Inf**	BDL	0.13	1.99	2.11	0.61	0.69	2.60	2.80	2.62
	Eff	BDL	BDL	1.51	1.66	0.19	0.03	1.70	1.70	1.81
7/14/03	**Inf**	BDL	0.08	1.60	1.69	1.10	0.61	2.70	2.30	2.64
	Eff	BDL	BDL	1.55	1.50	0.05	0	1.60	1.50	1.66
7/21/03	**Inf**	BDL	BDL	1.57	1.82	0.23	0.28	1.80	2.30	1.90
	Eff	BDL	BDL	1.78	1.90	0.02	0	1.80	1.90	1.82
7/28/03	**Inf**	BDL	BDL	2.30	1.45	0	0.05	2.50	1.50	2.35
	Eff	BDL	BDL	1.75	1.68	0.05	0.02	1.80	1.70	1.79
8/4/03	**Inf**	BDL	BDL	1.28	1.33	0.12	0.07	1.40	1.40	1.40
	Eff	BDL	BDL	1.17	1.20	0.04	0	1.20	1.20	1.20

Table 2-10 Continued

Week Ending		**Nitrate-N (mg/l)**		**Total Organic N (mg/l)**		**Ammonia N (mg/l)**		**TKN (mg/l)**		**Total Nitrogen (mg/l)**
		Day 1-6 Comp	Day 7 24-hr Comp	Day 1-6 Comp	Day 7 24-hr Comp	Day 1-6 Comp	Day 7 24-hr Comp	Day 1-6 Comp	Day 7 24-hr Comp	**Weekly Flow-Weighted**
8/11/03	**Inf**	BDL	BDL	2.03	0.93	0.27	0.09	2.30	1.02	2.11
	Eff	BDL	BDL	1.32	0.76	0.09	0.03	1.49	0.79	1.44
8/18/03	**Inf**	BDL	BDL	1.82	1.10	0.18	1.00	2.00	2.10	2.09
	Eff	0.10	BDL	1.19	1.23	0.21	0.07	1.40	1.30	1.47
8/25/03	**Inf**	BDL	BDL	2.94	1.96	0.16	0.34	3.10	2.30	3.01
	Eff	0.07	BDL	1.90	2.10	0.02	0.10	1.20	2.10	1.99
9/1/03	**Inf**	BDL	BDL	4.60	-	7.40	-	12.00	-	14.40
	Eff	BDL	BDL	1.90	-	0.10	-	2.00	-	1.96
9/8/03	**Inf**	BDL	BDL	1.90	2.61	0.45	0.29	2.90	2.40	2.90
	Eff	0.34	-	3.66	-	0.64	-	4.30	-	4.64
9/15/03	**Inf**	BDL	BDL	2.18	1.91	0.52	0.19	2.70	2.10	2.62
	Eff	BDL	0.04	1.90	2.18	0.20	0.01	2.10	2.20	2.46
9/22/03	**Inf**	BDL	0.05	2.28	2.25	0.22	0.05	2.28	2.25	2.50
	Eff	BDL	BDL	2.27	2.30	0.03	BDL	2.27	2.30	2.30
9/29/03	**Inf**	BDL	BDL	2.01	1.53	0.19	0.12	2.20	1.70	2.14
	Eff	BDL	BDL	1.54	1.77	0.06	0.03	1.60	1.80	1.63
10/6/03	**Inf**	BDL	0.03	1.77	1.66	0.27	0.32	1.90	1.80	1.89
	Eff	BDL	BDL	1.45	1.60	0.05	BDL	1.50	1.60	1.59
10/13/03	**Inf**	0.02	0.03	2.04	1.67	0.09	0.7	2.30	2.10	2.30
	Eff	0.17	BDL	2.00	1.60	0.03	BDL	2.00	2.00	2.15
10/20/03	**Inf**	0.02	BDL	2.00	2.10	0.14	BDL	2.00	2.10	2.02
	Eff	BDL	BDL	2.20	2.30	BDL	0.02	2.20	2.30	2.39
10/27/03	**Inf**	0.04	BDL	2.16	2.00	0.04	BDL	2.20	2.00	2.19
	Eff	0.02	BDL	1.88	2.00	0.02	BDL	1.90	2.00	1.91
11/3/03	**Inf**	BDL	BDL	2.34	2.34	0.05	0.16	2.40	2.40	2.40
	Eff	BDL	BDL	2.70	2.70	BDL	BDL	2.70	2.70	2.70

Table 2-10 Continued

Week Ending		Nitrate-N (mg/l)		Total Organic N (mg/l)		Ammonia N (mg/l)		TKN (mg/l)		Total Nitrogen (mg/l)
		Day 1-6 Comp	Day 7 24-hr Comp	Day 1-6 Comp	Day 7 24-hr Comp	Day 1-6 Comp	Day 7 24-hr Comp	Day 1-6 Comp	Day 7 24-hr Comp	**Weekly Flow-Weighted**
11/10/03	**Inf**	BDL		2.40	-	BDL	BDL	2.40	BDL	2.40
	Eff	0.58	-	3.00	-	BDL	BDL	3.00	BDL	3.48
11/17/03	**Inf**	0.19	0.26	2.05	1.90	0.06	BDL	2.10	1.90	2.26
	Eff	0.38	0.53	1.70	1.80	BDL	BDL	1.70	1.80	2.13
11/24/03	**Inf**	0.65	0.16	5.34	1.50	0.26	0.10	5.60	1.60	5.62
	Eff	0.45	0.51	1.80	1.90	BDL	BDL	1.80	1.90	2.27
12/1/03	**Inf**	0.73	0.18	2.01	1.41	0.19	0.09	2.20	1.50	2.75
	Eff	0.14	-	2.00	1.80	BDL	BDL	2.00	1.80	2.17
12/8/03	**Inf**	0.15	0.20	1.13	3.48	0.17	0.12	1.30	3.60	1.80
	Eff	0.89	0.92	1.50	1.30	BDL	BDL	1.50	1.30	2.37
12/15/03	**Inf**	0.15	-	0.99	1.27	0.11	0.13	1.10	1.40	1.26
	Eff	BDL	0.62	1.29	1.20	0.01	BDL	1.30	1.20	1.39
12/22/03	**Inf**	0.20	0.09	1.19	1.31	0.21	0.09	1.40	1.40	2.45
	Eff	0.82	1.10	1.33	1.50	0.07	BDL	1.40	1.50	1.58
12/29/03	**Inf**	-	-	-	-	BDL	BDL	BDL	BDL	1.53
	Eff	-	-	-	-	BDL	BDL	BDL	BDL	2.13
1/5/04	**Inf**	0.05	0.04	1.11	1.05	0.49	0.15	1.60	1.20	1.58
	Eff	0.45	0.34	1.44	1.30	0.06	BDL	1.50	1.30	1.93
1/12/04	**Inf**	-	0.06	-	1.21	BDL	0.09	BDL	1.30	1.59
	Eff	-	0.36	-	1.20	BDL	BDL	BDL	1.20	1.79
1/19/04	**Inf**	0.05	-	1.61	1.62	0.09	0.08	1.70	1.70	1.75
	Eff	0.40	0.19	1.90	1.60	BDL	BDL	1.90	1.60	2.24
1/26/04	**Inf**	0.23	0.11	1.22	1.47	0.18	0.13	1.40	1.60	1.64
	Eff	0.65	0.45	1.62	1.40	0.08	BDL	1.70	1.40	2.28
2/2/04	**Inf**	0.14	0.07	1.32	2.06	0.28	0.14	1.60	2.20	1.79
	Eff	0.69	0.54	1.78	1.30	0.03	BDL	1.80	1.30	2.39
2/9/04	**Inf**	0.10	0.06	1.20	1.18	0.30	0.02	1.50	1.20	1.81
	Eff	0.22	BDL	0.93	1.40	BDL	BDL	0.93	1.40	2.38
2/16/04	**Inf**	BDL	BDL	1.30	1.29	0.20	0.01	1.50	1.30	1.47
	Eff	BDL	BDL	1.30	1.30	BDL	BDL	1.30	1.30	1.30
2/23/04	**Inf**	BDL	BDL	1.12	1.10	0.08	BDL	1.20	1.10	1.19
	Eff	BDL	BDL	0.86	1.00	0.24	BDL	1.10	1.00	1.09
3/1/04	**Inf**	BDL	BDL	1.66	1.60	0.04	BDL	1.70	1.60	1.69
	Eff	BDL	BDL	1.40	1.60	BDL	BDL	1.40	1.60	1.42

Week Ending		**Nitrate-N (mg/l)**		**Total Organic N (mg/l)**		**Ammonia N (mg/l)**		**TKN (mg/l)**		**Total Nitrogen (mg/l)**
		Day 1-6 Comp	Day 7 24-hr Comp	Day 1-6 Comp	Day 7 24-hr Comp	Day 1-6 Comp	Day 7 24-hr Comp	Day 1-6 Comp	Day 7 24-hr Comp	**Weekly Flow-Weighted**
3/8/04	**Inf**	BDL	BDL	1.60	1.60	BDL	BDL	1.60	1.60	1.60
	Eff	BDL	BDL	1.50	1.10	BDL	BDL	1.50	1.10	1.45
3/15/04	**Inf**	BDL	BDL	1.03	1.19	0.07	0.01	1.10	1.20	1.12
	Eff	BDL	BDL	1.10	1.00	BDL	BDL	1.10	1.00	1.09
3/22/04	**Inf**	BDL	BDL	1.40	1.51	BDL	0.09	1.40	1.60	1.43
	Eff	BDL	BDL	1.18	1.19	0.02	0.02	1.20	1.20	1.20
3/29/04	**Inf**	BDL	BDL	1.92	1.89	0.08	0.01	2.00	1.90	1.99
	Eff	BDL	BDL	1.80	1.97	BDL	0.03	1.80	2.00	1.82
4/5/04	**Inf**	BDL	BDL	1.48	1.50	0.02	BDL	1.50	1.50	1.50
	Eff	BDL	BDL	1.35	1.28	0.05	0.02	1.40	1.30	1.39
4/12/04	**Inf**	BDL	BDL	1.54	1.39	0.16	0.01	1.70	1.40	1.62
	Eff	BDL	BDL	1.48	1.70	0.02	BDL	1.50	1.70	1.56
4/19/04	**Inf**	0.02	BDL	1.36	1.60	0.14	0.20	1.50	1.80	1.63
	Eff	BDL	BDL	1.20	1.20	BDL	BDL	1.20	1.20	1.20
4/26/04	**Inf**	0.03	BDL	1.25	1.25	0.15	0.05	1.40	1.30	1.41
	Eff	0.02	BDL	0.90	1.20	BDL	BDL	0.90	1.20	0.96
5/3/04	**Inf**	BDL	BDL	1.28	1.30	0.02	BDL	1.30	1.30	1.30
	Eff	BDL	BDL	0.97	1.00	BDL	BDL	0.97	1.00	0.97
5/10/04	**Inf**	BDL	BDL	1.40	0.82	BDL	0.06	1.40	0.88	1.33
	Eff	BDL	BDL	0.68	BDL	BDL	BDL	0.68	BDL	0.59
5/17/04	**Inf**	BDL	BDL	1.25	1.24	0.15	0.06	1.40	1.30	1.34
	Eff	0.02	BDL	1.07	1.10	0.03	BDL	1.10	1.10	1.12
5/24/04	**Inf**	BDL	BDL	1.58	1.70	0.12	BDL	1.70	1.70	1.70
	Eff	BDL	BDL	1.50	1.18	BDL	BDL	1.50	1.20	1.52
5/31/04	**Inf**	0.21	BDL	2.42	1.58	0.28	0.22	2.70	1.80	2.59
	Eff	0.23	0.02	1.45	1.48	0.05	0.02	1.50	1.50	1.70

Table 2-10 Continued

Week Ending		Nitrate-N (mg/l)		Total Organic N (mg/l)		Ammonia N (mg/l)		TKN (mg/l)		Total Nitrogen (mg/l)
		Day 1-6 Comp	Day 7 24-hr Comp	Day 1-6 Comp	Day 7 24-hr Comp	Day 1-6 Comp	Day 7 24-hr Comp	Day 1-6 Comp	Day 7 24-hr Comp	Weekly Flow-Weighted
06/07/04	Inf	0.058	0.039	2.060	2.400	0.340	0.200	2.4	2.60	**2.60**
	Eff	-	0.19	-	1.86	BDL	0.05	1.20	1.90	**1.96**
06/14/04	Inf	0.058	0.120	1.590	1.770	0.210	0.430	1.8	2.20	**2.26**
	Eff	0.350	0.46	1.164	1.10	0.036	BDL	1.20	1.10	**1.56**
06/21/04	Inf	0.041	0.043	1.120	1.640	0.180	0.360	1.7	2.00	**1.94**
	Eff	0.045	0.33	1.461	1.39	0.039	0.11	1.90	1.50	**1.80**
06/28/04	Inf	BDL	0.018	1.530	1.640	0.070	0.260	1.6	1.90	**1.87**
	Eff	BDL	0.29	1.300	1.48	BDL	0.02	1.30	1.50	**1.78**
07/05/04	Inf	0.023	0.028	1.580	1.490	0.120	0.110	1.7	1.60	**1.68**
	Eff	0.590	0.35	1.806	1.57	0.094	0.03	1.90	1.60	**1.97**
07/12/04	Inf	BDL	BDL	1.110	1.280	0.190	0.120	1.3	1.40	**1.38**
	Eff	BDL	0.11	1.284	1.30	0.016	BDL	1.30	1.30	**1.42**
07/19/04	Inf	BDL	0.240	1.300	1.178	BDL	0.022	1.3	1.20	**1.30**
	Eff	0.055	BDL	1.000	1.23	BDL	0.07	1.00	1.30	**1.38**
07/26/04	Inf	BDL	BDL	1.365	1.000	0.035	0.070	1.4	1.10	**1.15**
	Eff	BDL	0.04	1.100	1.20	BDL	BDL	1.10	1.20	**1.22**
08/02/04	Inf	BDL	BDL	1.276	1.370	0.024	0.130	1.3	1.500	**1.47**
	Eff	0.020	0.06	0.980	1.08	BDL	0.02	0.98	1.10	**1.13**
08/09/04	Inf	BDL	BDL	1.341	1.011	0.590	0.890	1.4	1.10	**1.14**
	Eff	BDL	0.04	BDL	1.10	BDL	BDL	1.00	1.10	**1.10**
08/16/04	Inf	BDL	BDL	1.110	1.290	0.190	0.510	1.3	1.80	**1.70**
	Eff	0.021	0.05	1.070	1.25	0.030	0.05	1.10	1.30	**1.30**
08/23/04	Inf	BDL	BDL	2.410	1.650	0.190	0.350	2.60	28.00	**2.09**
	Eff	BDL	0.42	1.871	3.37	0.029	0.13	1.90	3.50	**3.30**
08/30/04	Inf	BDL	BDL	2.100	1.950	0.400	0.750	2.5	2.70	**2.66**
	Eff	BDL	BDL	2.590	2.42	0.009	0.08	2.60	2.50	**2.59**
09/09/04	Inf	-	BDL	-	1.16	-	0.84	-	2.00	**2.00**
	Eff	-	0.06	-	1.60	-	1.60	-	3.20	**2.51**
09/20/04	Inf	BDL	BDL	2.410	2.310	0.290	0.690	2.7	3.00	**2.88**
	Eff	-	0.15	1.373	1.91	0.027	0.19	1.40	2.10	**1.97**
09/27/04	Inf	-	BDL	-	1.920	-	0.480	-	2.40	**1.81**
	Eff	0.054	0.13	-	1.80	-	0.10	-	1.90	**1.67**
10/11/04	Inf	BDL	0.076	1.020	1.808	0.180	0.092	1.2	1.90	**1.88**
	Eff	-	BDL	1.888	2.39	0.012	0.31	1.90	2.70	**2.60**
10/18/04	Inf	BDL	BDL	1.720	2.04	0.080	0.16	1.8	2.20	**2.15**
	Eff	0.034	0.110	1.900	2.050	BDL	0.050	1.90	2.100	**2.17**

Table 2-11: WHS™ effluent water quality nitrogen data collected as grab samples for the period February 3, 2003 through October 18, 2004

Week Ending (Q1)	2/3	2/10	2/17	2/24	3/3	3/10	3/17	3/24	3/31	4/7	4/14	4/21	4/28	5/5
WHS™ Effluent TKN (mg/l)	1.80	1.60	1.80	1.40	1.60	1.60	2.10	1.00	4.10	1.90	1.70	1.20	1.20	1.10
WHS™ Effluent Nitrate-N (mg/l)	BDL	BDL	BDL	BDL	0.18	BDL	BDL	10.00	BDL	0.21	0.15	BDL	0.19	0.29
WHS™ Effluent Nitrite-N (mg/l)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Week Ending (Q2)	5/12	5/19	5/26	6/2	6/9	6/16	6/23	6/30	7/7	7/14	7/21	7/28	8/4
WHS™ Effluent TKN (mg/l)	1.00	1.20	1.30	1.60	1.30	1.30	1.40	1.50	1.70	1.70	1.80	1.50	1.30
WHS™ Effluent Nitrate-N (mg/l)	0.11	0.2	0.44	0.29	0.34	0.16	0.29	0.08	BDL	BDL	0.03	BDL	0.07
WHS™ Effluent Nitrite-N (mg/l)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Week Ending (Q3)	8/11	8/18	8/25	9/1	9/8	9/15	9/22	9/29	10/6	10/13	10/20	10/27	11/3
WHS™ Effluent TKN (mg/l)	1.50	1.30	2.10	1.70	1.60	-	1.80	1.60	1.50	2.20	2.20	1.9	2.50
WHS™ Effluent Nitrate-N (mg/l)	0.17	BDL	0.04	BDL	0.10	-	0.06	0.09	0.07	0.28	0.33	0.26	0.99
WHS™ Effluent Nitrite-N (mg/l)	BDL	BDL	BDL	BDL	BDL	-	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Week Ending (Q4)	11/10	11/17	11/24	12/1	12/8	12/15	12/22	12/29	1/5	1/12	1/19	1/26
WHS™ Effluent TKN (mg/l)	1.50	2.70	2.10	1.40	1.20	1.50	1.40	1.50	0.72	1.80	2.20	2.00
WHS™ Effluent Nitrate-N (mg/l)	0.44	0.77	1.00	0.96	0.59	-	0.47	0.41	0.43	0.55	0.56	0.56
WHS™ Effluent Nitrite-N (mg/l)	BDL	BDL	BDL	BDL	BDL	-	BDL	BDL	0.05	BDL	BDL	BDL

Week Ending (Q5)	2/2	2/9	2/16	2/23	3/1	3/8	3/15	3/22	3/29	4/5	4/12	4/19	4/26	5/3	5/10	5/17	5/24	5/31
WHS™ Effluent TKN (mg/l)	2.00	1.30	1.30	1.20	1.30	1.20	0.99	1.30	1.80	1.30	1.20	1.00	1.00	0.88	0.58	1.20	1.00	1.30
WHS™ Effluent Nitrate-N (mg/l)	0.56	0.04	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.04	BDL	BDL	BDL	BDL	BDL	0.04	0.18
WHS™ Effluent Nitrite-N (mg/l)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Week Ending (Q6)	6/7	6/14	6/21	6/28	7/5	7/12	7/19	7/26	8/2	8/9	8/16	8/23	8/30	9/9	9/20	9/27	10/11	10/18
WHS™ Effluent TKN (mg/l)	0.13	0.15	0.10	BDL	0.04	0.13	0.06	BDL	0.03	0.03	0.05	BDL	0.02	-	0.16	-	-	0.12
WHS™ Effluent Nitrate-N (mg/l)	1.00	0.88	1.00	1.10	0.77	1.30	0.90	1.00	1.20	0.89	0.91	1.90	2.00	-	1.80	-	-	1.60
WHS™ Effluent Nitrite-N (mg/l)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	-	BDL	-	-	BDL

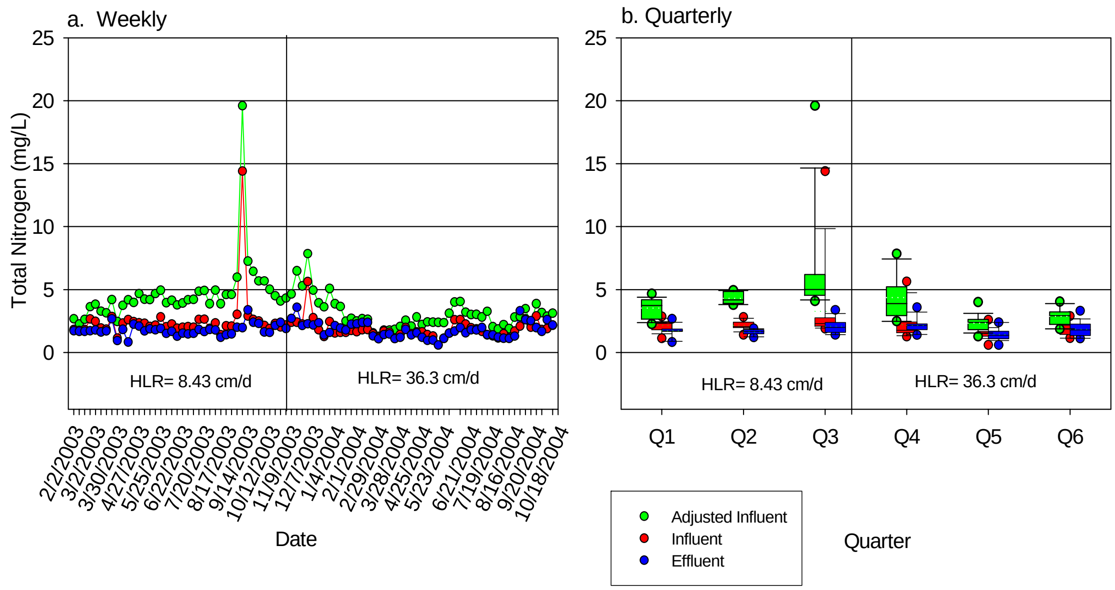


Figure 2-14: Influent and effluent weekly flow-weighted total nitrogen concentrations for the period January 27, 2003 through October 18, 2004.

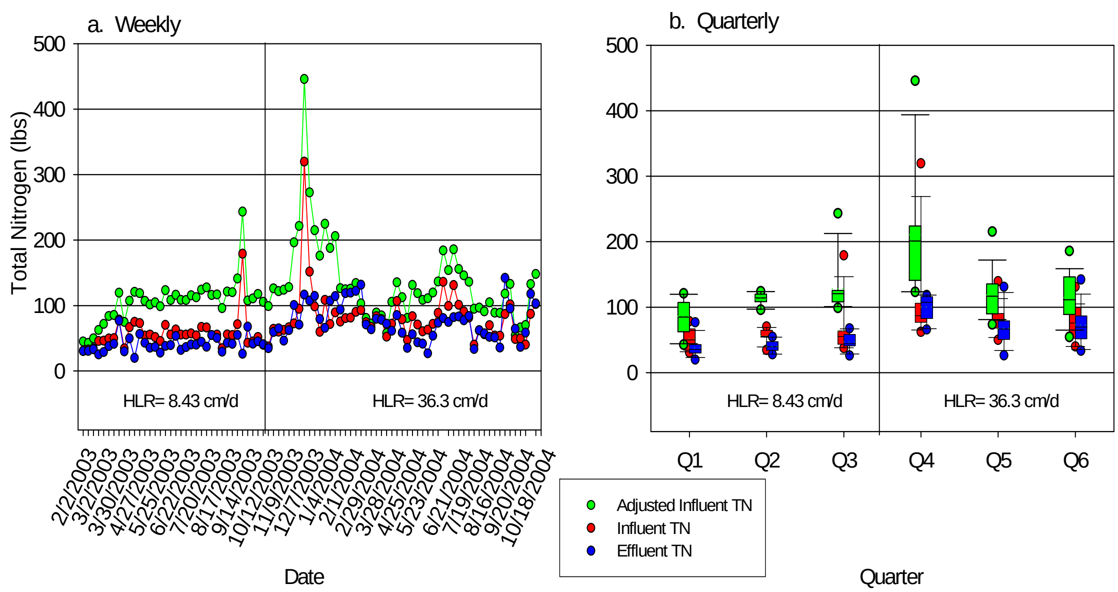


Figure 2-15: Influent and effluent weekly flow-weighted total nitrogen load for the period January 27, 2003 through May 31, 2004 a. Weekly b. Quarterly

N:P ratio

The ratio of nitrogen to phosphorus is noted to change significantly from the influent to the effluent as noted in Figure 2-16. For Q1 the average N:P ratio for the influent was 4.3:1, increasing to6.95 when adjusted for supplemented nitrogen, and then increasing further to 23.25:1 for the effluent. For Q2 the average N:P ratio for the influent was 5.56:1,11.4 for the supplemented influent, increasing to 29.98:1 for the effluent. For Q3 the average N:P ratio for the influent was 6.91:1, 13.8-for the supplemented influent, increasing to 25.45:1 for the effluent. In Q4, Q5 and Q6, the N:P influent ratios were 14.20:1, 6.93:1, and 10.69:1, respectively, the supplemented influent ratios were 29.3,9.9, and 17.3 respectively, while effluent N:P ratios were 29.13:1 and 13.61:1 and 21.57:1 respectively. For the combined periods, the average N:P ratio for the influent was 8.10:1 increasing to14.33 for the supplemented influent, and increasing further to 23.1:1 for the effluent. There is a notable decline in effluent N:P ratio during the disruptive event of July, as a result of reductions in phosphorus removal. An increase in influent N:P ratio is noted during Q3. Influent N:P is more variable under the high loading rate regime. However, effluent N:P shows slightly less variability during Q4 and Q5 than in the previous three quarters

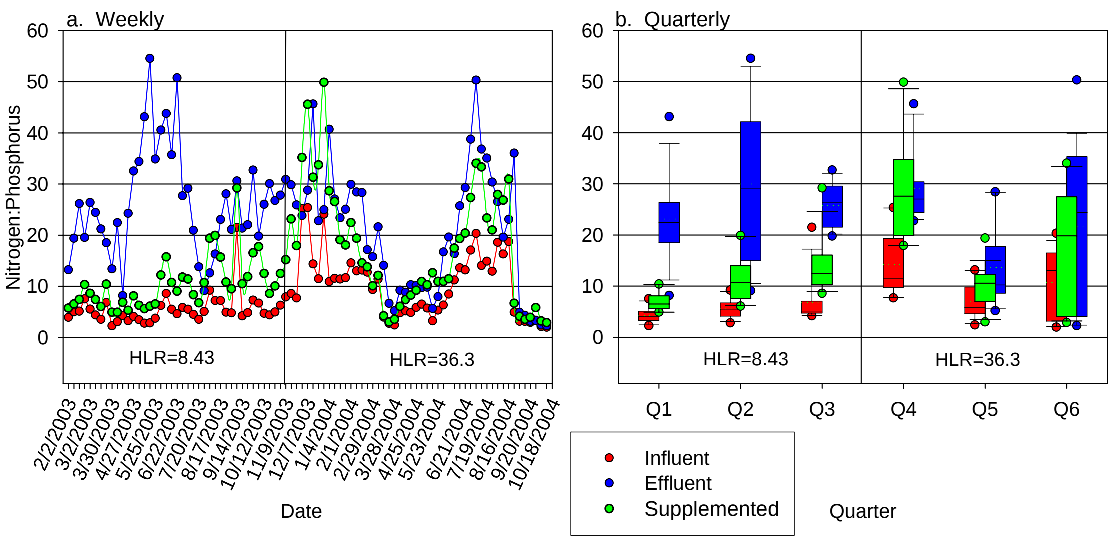


Figure 2-16: Influent and effluent N:P ratios based for the period January 27, 2003 through October 18 , 2004.

Conductivity and Dissolved Solids

Conductivity patterns are noted for the ATS™-WHS™ Treatment system influent and effluent within Figures 2-17through 2-20. These graphs represent diurnal composites taken from the continuous monitoring element associated with both the influent and effluent samplers. A comparison of field data taken with a hand held meter to the sampler data for January 2003 through May 2004 are noted as Figure 2-23. As autosampler data was not available for the entire period during Q6, it is not reported. Data associated with the handheld device is comparable to that associated with the autosampler (as shown in Figure 2-23) and is used as the source data for conductivity, and pH for Q6. There is a very discernible decrease in conductivity during Q3 and Q6, attributable most likely to the heavy rainfall during this period. In addition, there is a noticeable differential between influent and effluent conductivity during Q3, which is likely due to the wide differential between influent and effluent temperatures (see Figures 2-2 and 2-3). Conductivity in quarters four and five overall remained lower than that observed in quarters one and two. As conductivity is impacted directly by temperature, total dissolved solids serves as a somewhat more effective indicator of changes in mineral content. These data are relative to the balance between mineral supplementation; influence of ET losses, rainfall and infiltration; and direct plant uptake.

Total Dissolved solids (TDS) trends are noted within Table 2-12 and Figure 2-21. It is notable that the differential between influent and effluent TDS is not as pronounced as with conductivity, indicating as noted, the influence of temperature. Samples analyzed for TDS were the flow-proportionate 6-day composite samples collected via the Sigma 900 Max automatic refrigerated samplers. Conductivity trends for the POR are also noted within the graphs presented as Appendix 2.

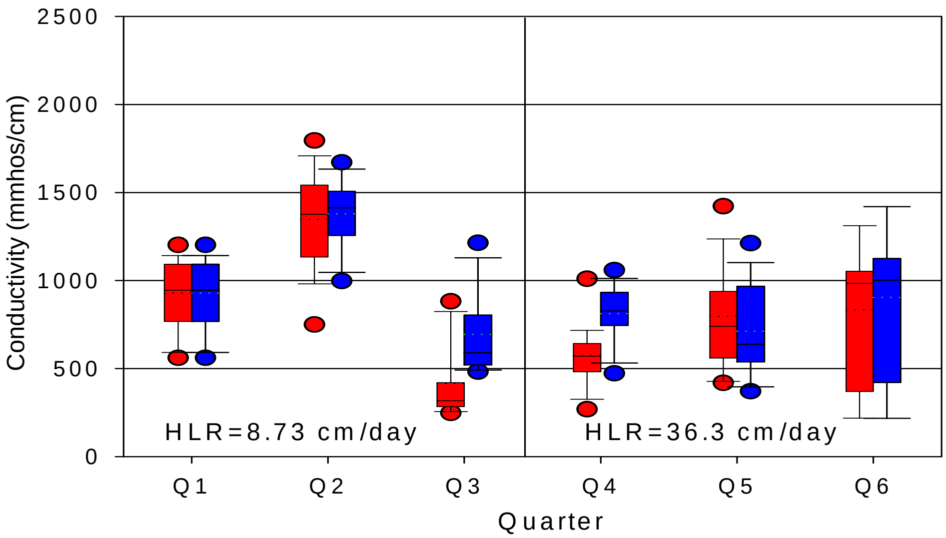


Figure 2-17: Mean quarterly conductivity for the period of record, which represents the period of January 27, 2003 through October 18, 2004.

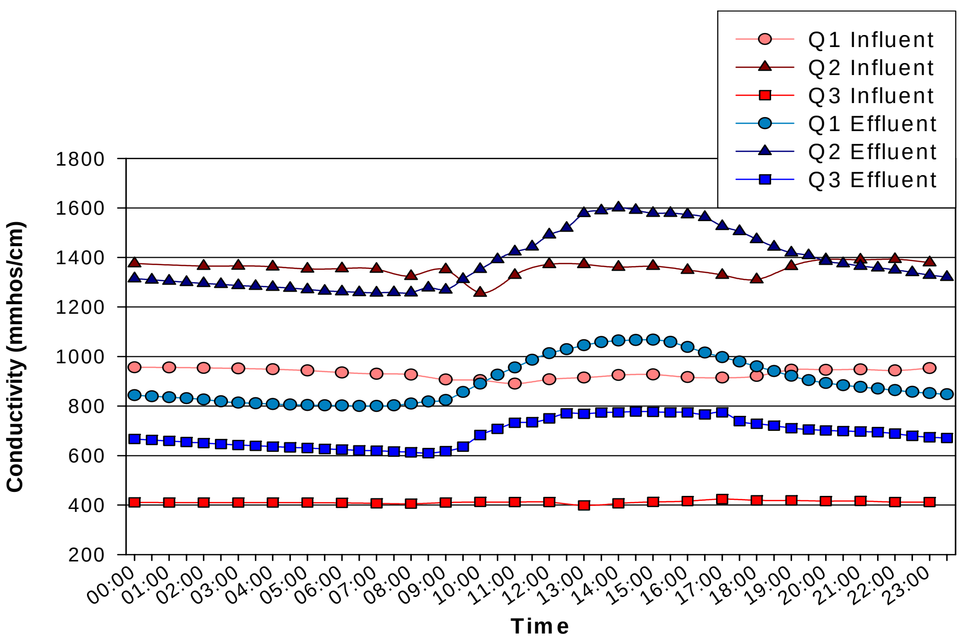


Figure 2-18: Mean influent and effluent diurnal conductivity for Quarters 1-3, which represents the period of January 27, 2003 to November 3, 2004.

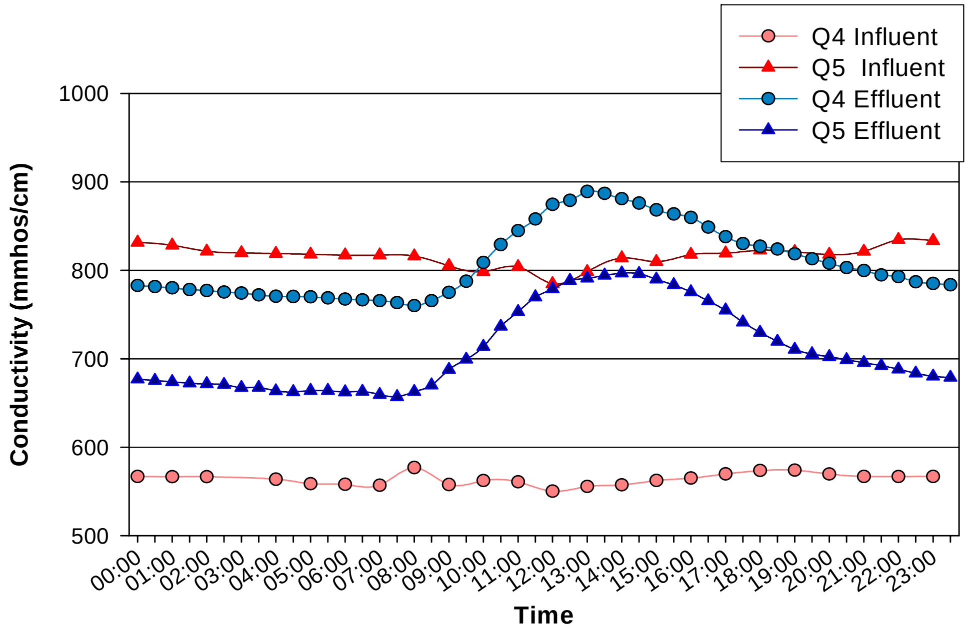


Figure 2-19: Mean influent and effluent diurnal conductivity for Quarter 4-5, which represents the period of November 3, 2003 to May 31, 2004.

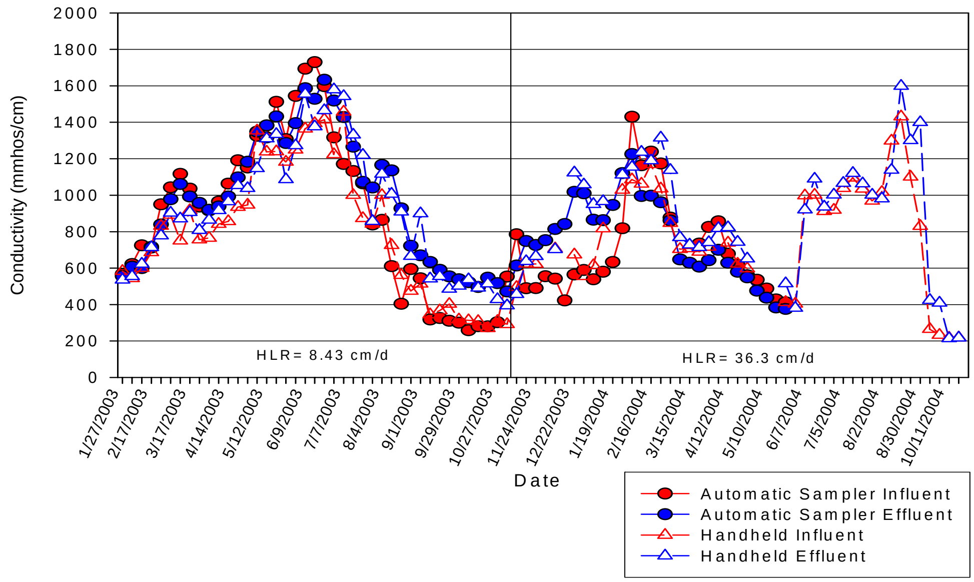


Figure 2-20: Comparison of field meter (hand-held) and autosampler conductivity measurements for the period January 27,2003 throughOctober 18, 2004.

Table 2-12: Influent and effluent total dissolved solids concentrations for the period January 27, 2003 through October 18, 2004.

Week Ending	2/3	2/10	2/17	2/24	3/3	3/10	3/17	3/24	3/31	4/14	4/21	4/28	5/5
Influent Total Dissolved Solids (TDS) mg/l	340	440	430	510	540	590	610	560	480	640	690	690	730
Effluent Total Dissolved Solids (TDS) mg/l	350	390	430	460	510	570	460	540	570	600	600	620	660

Week Ending	5/12	5/19	5/26	6/2	6/9	6/16	6/23	6/30	7/7	7/14	7/21	7/28	8/4
Influent Total Dissolved Solids (TDS) mg/l	970	1200	990	810	830	1100	1100	970	870	750	680	600	720
Effluent Total Dissolved Solids (TDS) mg/l	930	1000	890	780	840	1100	950	1100	1000	940	800	650	630

Week Ending	8/11	8/18	8/25	9/1	9/8	9/15	9/22	9/29	10/6	10/13	10/20	10/27	11/3
Influent Total Dissolved Solids (TDS) mg/l	720	1000	710	450	590	340	330	280	320	260	260	250	280
Effluent Total Dissolved Solids (TDS) mg/l	630	720	730	590	510	BDL	330	350	330	340	300	330	320

Week Ending	11/10	11/17	11/24	12/1	12/8	12/15	12/22	12/29	1/5	1/12	1/19	1/26
Influent Total Dissolved Solids (TDS) mg/l	280	490	360	450	480	520	660	-	580		550	630
Effluent Total Dissolved Solids (TDS) mg/l	260	390	390	450	460	510	620	-	650	-	530	610

Table 2-12: Continued

Week Ending	2/2	2/9	2/16	2/23	3/1	3/8	3/15	3/22	3/29	4/5	4/12	4/19
Influent Total Dissolved Solids (TDS) mg/l	850	1000	800	740	830	600	520	470	450	540	580	500
Effluent Total Dissolved Solids (TDS) mg/l	790	790	760	750	770	620	520	500	440	550	560	540

Week Ending	4/26	5/3	5/10	5/17	5/24	6/1
Influent Total Dissolved Solids (TDS) mg/l	450	410	330	330	310	340
Effluent Total Dissolved Solids (TDS) mg/l	500	400	400	340	300	290

Week Ending	6/7	6/14	6/21	6/28	7/5	7/12	7/19	7/26	8/2	8/9	8/16	8/23	8/30	9/9	9/20	9/27	10/11	10/18
Influent Total Dissolved Solids (TDS) mg/l	280	820	690	600	600	660	810	730	680	750	1300	1200	900	430	180	140	150	160
Effluent Total Dissolved Solids (TDS) mg/l	290	600	730	640	670	640	260	720	680	690	820	1100	890	560	250	160	130	170

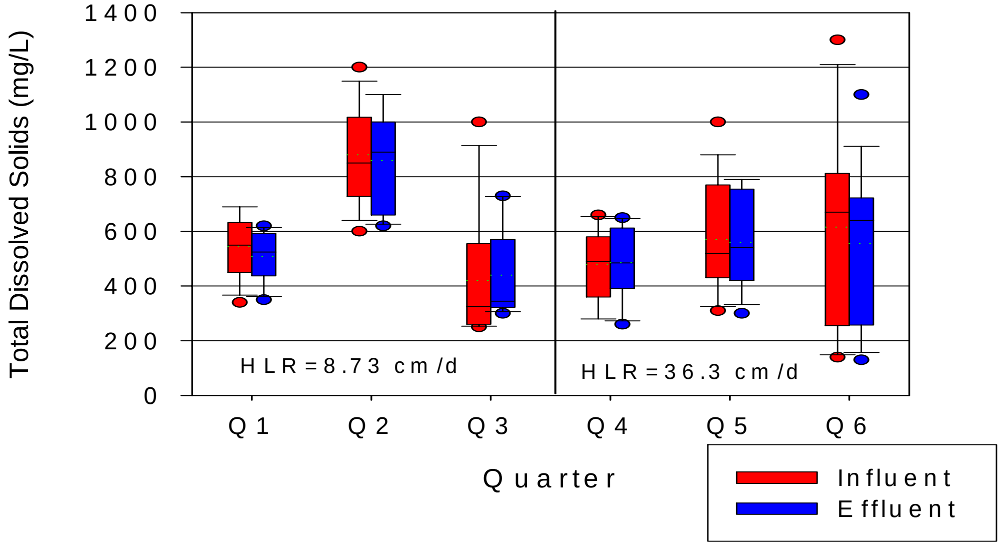


Figure 2-21: Influent and effluent total dissolved solids concentrations for the period April 28, 2003 through October 18, 2004.

Suspended Solids and Organic Loads

The total suspended solids and total volatile (organic) suspended solids for influent and effluent samples are noted in Table 2-13 and Figure 2-22. BOD_5 and TOC are also shown in Table 2-13. Samples analyzed for suspended solids and TOC were the flow-proportionate 6-day composite samples collected via the Sigma 900 refrigerated automatic samplers. Samples analyzed for BOD_5 were the Day-7 flow-proportionate 24-hr composite. In general there is a decline in suspended solids through the system, with TOC relatively unchanged. The BOD_5 levels are typically very low in both the influent and effluent, although a few outliers are noted during Q3, as shown in Table 2-13. It is possible that the nature of the organic compounds does change through the process, with incoming organics associated with recalcitrant organics, while effluent organics would be expected to be associated with algae, and hence less recalcitrant. This is noted by the shift in the TOC/BOD ratio from 8.17 (sd = 3.8) for the influent to 7.17 (sd = 3.01) in the effluent—the lower ratio indicating a greater degree of biodegradability. As a general observation, the organic load associated with L-62 can be considered low, and at the levels both in the influent and the effluent, are not likely contributory to water quality degradation within Lake Okeechobee.

Table 2-13: Influent and effluent total suspended solids (TSS), total volatile suspended solids (TVSS), total organic carbon (TOC) and biochemical oxygen demand (BOD) for the period January 27, 2003 through October 18, 2004.

Week Ending	2/3	2/10	2/17	2/24	3/3	3/10	3/17	3/24	3/31	4/7	4/14	4/21	4/28	5/5
Influent Total Suspended Solids (TSS) mg/l	5	12	9	16	28	33	12	9	8	5	5	11	15	18
Effluent Total Suspended Solids (TSS) mg/l	BDL	BDL	BDL	4	BDL	BDL	11	3	4	3	BDL	6	4	4
Influent Total Volatile Suspended Solids (TVSS) mg/l	3	8	5	11	14	18	5	7	BDL	4	8	6	8	12
Effluent Total Volatile Suspended Solids (TVSS) mg/l	BDL	BDL	BDL	3	BDL	BDL	10	3	BDL	4	3	2	BDL	4
Influent Total Organic Carbon (TOC) mg/l	26	28	29	29	28	30	35	30	32	30	28	36	27	30
Effluent Total Organic Carbon (TOC) mg/l	29	29	31	28	29	29	21	25	31	35	31	31	28	27
Influent Biochemical Oxygen Demand (BOD) mg/l	2	2	30	5	3	3	4	4	2	5	3	4	4	4
Effluent Biochemical Oxygen Demand (BOD) mg/l	4	4	6	3	3	4	3	3	4	6	4	5	4	6

Table 2-13: Continued

Week Ending	5/12	5/19	5/26	6/2	6/9	6/16	6/23	6/30	7/7	7/14	7/21	7/28	8/4
Influent Total Suspended Solids (TSS) mg/l	8	13	7	10	7	7	6	7	5	18	6	8	5
Effluent Total Suspended Solids (TSS) mg/l	BDL	5	4	3	3	BDL	BDL	4	BDL	4	12	6	4
Influent Total Volatile Suspended Solids (TVSS) mg/l	8	11	7	6	8	BDL	6	7	5	9	6	8	5
Effluent Total Volatile Suspended Solids (TVSS) mg/l	BDL	5	4	2	4	BDL	BDL	4	BDL	4	11	6	4
Influent Total Organic Carbon (TOC) mg/l	30	37	30	30	23	26	26	30	28	31	32	25	27
Effluent Total Organic Carbon (TOC) mg/l	27	30	27	27	30	24	24	29	24	39	39	29	30
Influent Biochemical Oxygen Demand (BOD) mg/l	5	5	7	7	12	24	4	5	10	7	7	5	4
Effluent Biochemical Oxygen Demand (BOD) mg/l	6	16	7	5	4	4	6	11	4	16	16	9	7

Table 2-13: Continued

Week Ending	8/11	8/18	8/25	9/1	9/8	9/15	9/22	9/29	10/6	10/13	10/20	10/27	11/3
Influent Total Suspended Solids (TSS) mg/l	10	19	8	12	6	7	5	8	6	6	4	4	5
Effluent Total Suspended Solids (TSS) mg/l	3	4	BDL	5	BDL	4	4	5	4	3	3	3	6
Influent Total Volatile Suspended Solids (TVSS) mg/l	9	11	8	11	6	4	3	8	6	6	4	4	3
Effluent Total Volatile Suspended Solids (TVSS) mg/l	BDL	4	BDL	5	BDL	BDL	BDL	5	3	BDL	3	3	6
Influent Total Organic Carbon (TOC) mg/l	28	33	36	39	120*	38	30	32	31	29	27	32	29
Effluent Total Organic Carbon (TOC) mg/l	25	24	31	32	28	37	35	31	30	31	30	33	31
Influent Biochemical Oxygen Demand (BOD) mg/l	4	4	3	4	77*	3	3	44*	2	5	3	5	2
Effluent Biochemical Oxygen Demand (BOD) mg/l	17	17	6	5	2	9	5	>77*	6	5	5	5	3

Table 2-13: Continued

Week Ending	6/7	6/14	6/21	6/28	7/5	7/12	7/19	7/26	8/2
Influent Total Suspended Solids (TSS) mg/l	20	15	13	10	8	9	6	10	9
Effluent Total Suspended Solids (TSS) mg/l	14	5	5	4	6	7	5	7	7
Influent Total Volatile Suspended Solids (TVSS) mg/l	13	10	10	9	7	8	0	9	8
Effluent Total Volatile Suspended Solids (TVSS) mg/l	2	9	5	4	5	7	0	7	7
Influent Total Organic Carbon (TOC) mg/l	24	27	26	23	23	24	24	24	23
Effluent Total Organic Carbon (TOC) mg/l	22	20	24	22	24	22	23	22	22
Influent Biochemical Oxygen Demand (BOD) mg/l	4	4	4	4	3	4	3	BDL	BDL
Effluent Biochemical Oxygen Demand (BOD) mg/l	3	2	4	3	3	BDL	2	BDL	BDL

Table 2-13: Continued

Week Ending	8/9	8/16	8/23	8/30	9/9	9/20	9/27	10/11	10/18
Influent Total Suspended Solids (TSS) mg/l	7	6	7	5	2	10	6	16	6
Effluent Total Suspended Solids (TSS) mg/l	7	6	7	30	12	17	6	6	6
Influent Total Volatile Suspended Solids (TVSS) mg/l	7	5	7	5	2	9	6	13	6
Effluent Total Volatile Suspended Solids (TVSS) mg/l	7	6	6	19	12	16	6	5	10
Influent Total Organic Carbon (TOC) mg/l	22	21	33	36	25	29	32	29	29
Effluent Total Organic Carbon (TOC) mg/l	20	19	26	38	30	29	29	29	30
Influent Biochemical Oxygen Demand (BOD) mg/l	BDL	3	5	BDL	BDL	8	5	5	3
Effluent Biochemical Oxygen Demand (BOD) mg/l	BDL	3	2	BDL	BDL	6	3	4	4

*Potential outliers

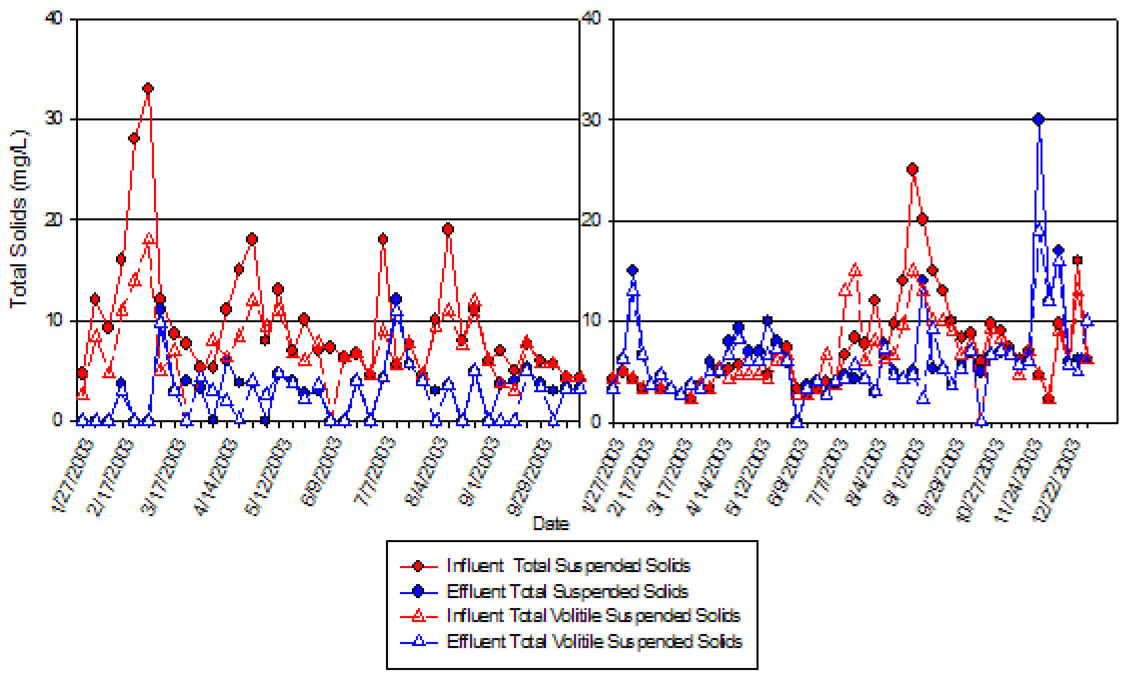


Figure 2-22 Influent and effluent total suspended solids concentrations for the period January 27, 2003 through May 31, 2004.

pH and Alkalinity

The WHS™ - ATS™ system influent and effluent pH were monitored in-situ via the Sigma 900 Max automatic refrigerated samplers located at the effluent and influent Parshall flumes, and recorded every 30 minutes. In addition, daily field recordings were made using hand held instruments. Field sampling locations include:

- Influent Parshall Flume
- WHS™ effluent north and south
- ATS™ effluent north and south, prior to microscreen
- ATS™ influent at recycle pump station (this includes recycled flows mixed with WHS™ effluent during Q1-Q3)

Alkalinity was determined on the 6-day flow-proportionate composite sample taken by the automatic Sigma 900 Max samplers, for both influent and effluent. In addition, for the first quarter, test strips were taken for alkalinity in the field at the same stations and time as the field pH recordings. These strip tests were discontinued during the second quarter because of the limited value of the information, and the low reliability of the test.

The pH for influent and effluent by quarter is plotted in Figure 2-23. Comparative graphs of the diurnal influent and effluent pH values are presented in Figure 2-24 and 2-25 with the exception of Quarter 6. Influent and effluent pH graphical output for the automatic samplers is included in Appendix 3. The significant variation in pH within the effluent is associated primarily with the utilization of carbon dioxide during the daylight period by the algal biomass, as is discussed in further detail within the section entitled "Review of pH Fluctuations, Alkalinity and Carbon Availability". The field data as noted within Figure 2-26 reflects the influence of the algae production upon pH. The samples included in this graph are those taken in the afternoon when productivity is typically the highest. The day-6 composite samples taken by the automatic refrigerated sampler were analyzed for alkalinity as well, as noted in Figure 2-27. The influence of the termination of recycling in November, 2003 is clearly noted in Figure 2-26 by the downward pH shift of the ATS™ pump station flows.

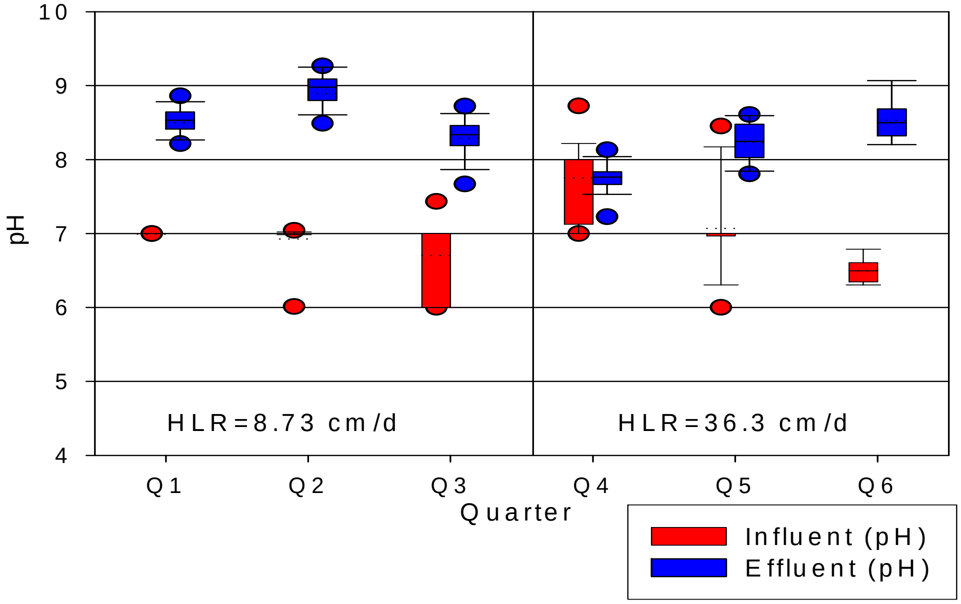


Figure 2-23: Mean Quarterly pH for the period of January 27, 2003 through October 18, 2004.

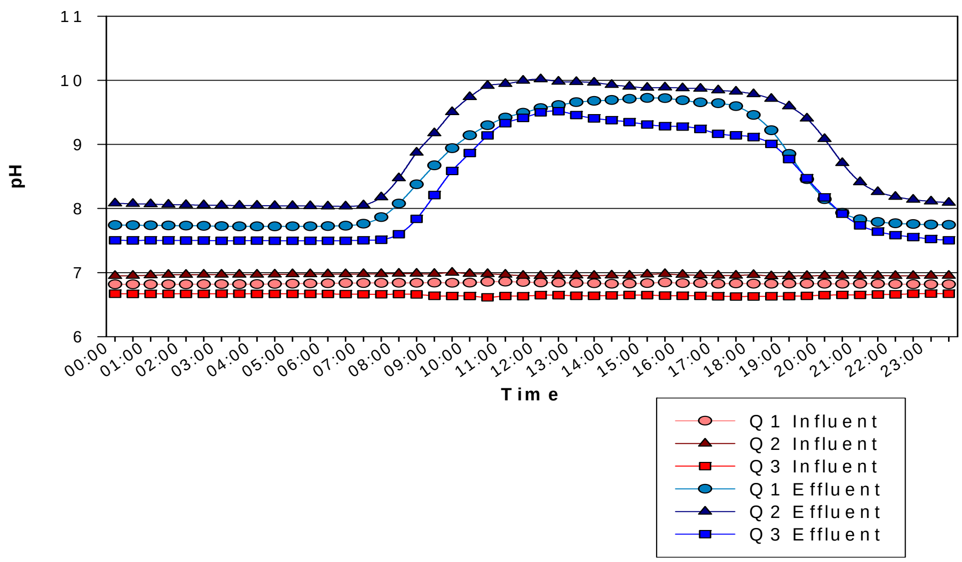


Figure 2-24: Influent and effluent mean diurnal pH for Quarters 1-3, representing the period of January 27, 2003 through November 3, 2003.

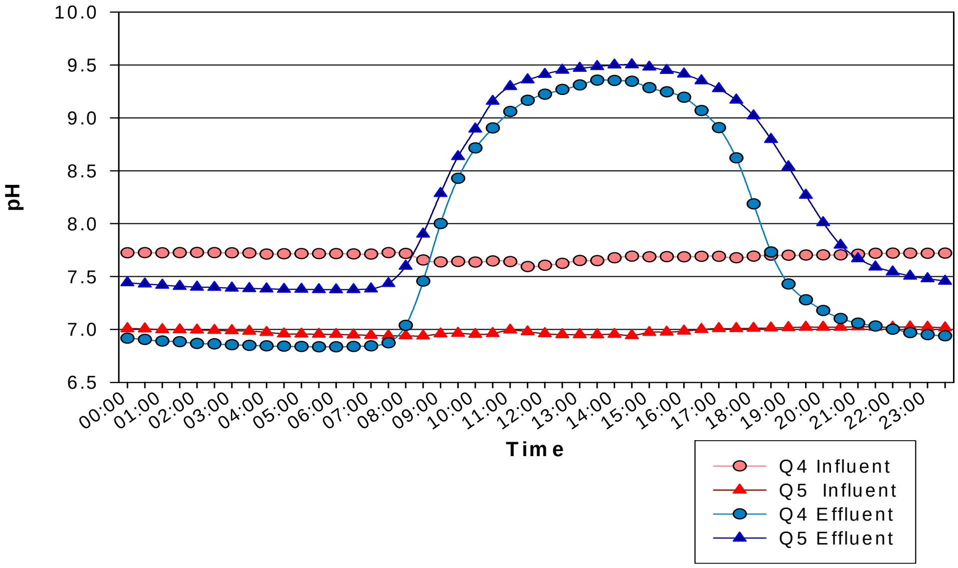


Figure 2-25: Influent and effluent mean diurnal pH for Quarters 4 and 5, representing the period November 3, 2003 to October 18, 2004.

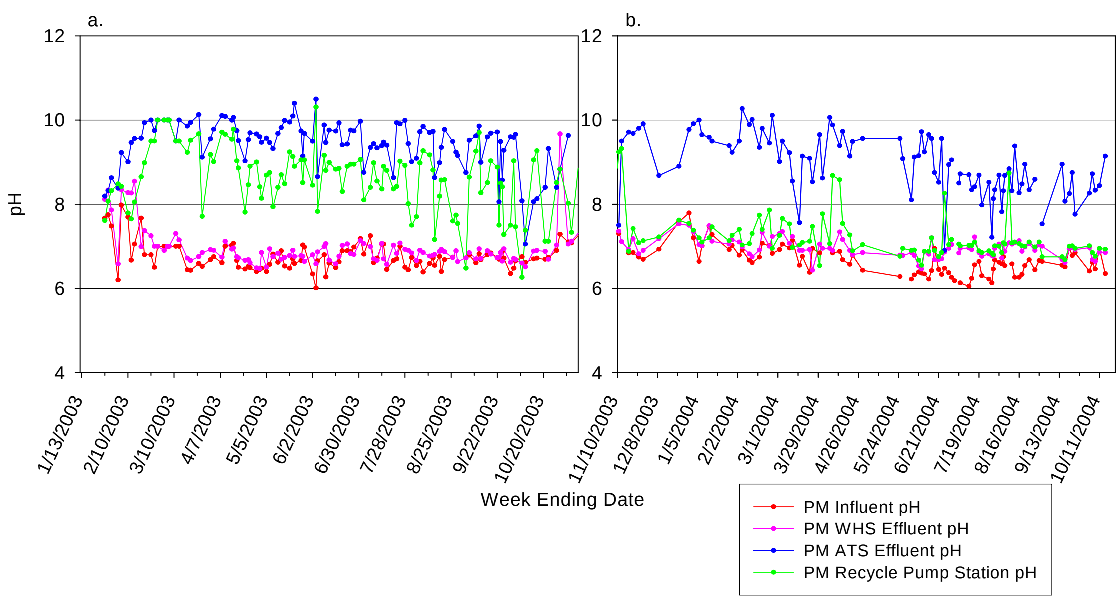


Figure 2-26: PM pH field monitoring stations data for the period of January 27, 2003 through October 18, 2004.

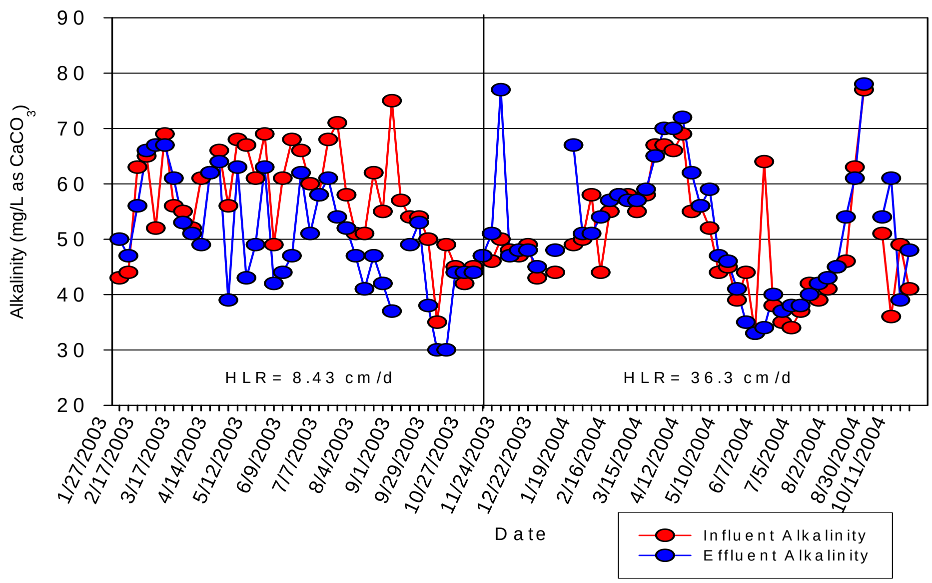


Figure 2-27: Influent and effluent alkalinity for the period of January 27, 2003 through October 18 2004.

Temperature and Dissolved Oxygen

Changes in water temperature were briefly discussed previously in the section entitled "Analysis of Flows". As noted, water temperature in the ATS™ system effluent closely tracks air temperature during daily shifts. This is related to the large heat exchange opportunity provided by the laminar flow across the ATS™. Accordingly, the variation in temperature within the system effluent is considerably greater than that observed in the influent. This is noted within the average temperature data included within Table 2-14 and within the Sigma 900 automatic refrigerated sampler output included in Appendix 4.

While the ATS™ clearly impacts diurnal temperature fluctuations, its influence on net change in mean temperature is not as dramatic, as noted from review of Table 2-14. This influence resulted in a slight cooling of the effluent water in six of the first nine months, with a slight increase in mean effluent water temperature noted for February, August and October 2003, when compared to mean influent water temperature. The average water temperatures increased noticeably through the second quarter, as the water mass provides heat storage during the summer months. The average water temperature began to drop through the third quarter, after peaking in July.

Water temperatures continued to drop through Quarter 4 where average influent and effluent water temperatures were 17.5 and 16.9 degrees C, respectively. Quarter 5 began as ambient air temperatures began to climb, and accordingly rose to an inflow mean of 23.6 degrees C. A noticeable decrease in effluent temperature was observed during Q5, most likely due to operational changes, which eliminated the recirculation of water upon the ATS™. As stated, autosampler data for influent flume temperature is not available for Q6, but handheld temperature readings indicate increased influent and effluent water temperature readings (mean 27.7^{o} C and 28.4^{o} C respectively) with mean air temperature of 26.1 ^{o} C.

Dissolved oxygen of course is also influenced by temperature, with saturation concentrations directly dependent upon temperature. The dynamics of dissolved oxygen within the system is influenced by several phenomena, which include:

- Shading in L-62 by extensive duckweed cover, which also inhibits atmospheric reaeration. Benthic oxygen demand could well impact L-62 DO levels.
- Shading in the WHS™ by the hyacinth biomass, which also inhibits atmospheric reaeration.
- Maintenance of 20-40% open water in the WHS™ permits some atmospheric reaeration within the unit.
- Algae production on the ATS™ results in extensive oxygen production and may result in super saturation during the daytime.
- Algae respiration on the ATS™ at nighttime and the cessation of photosynthesis imposes upon dissolved oxygen levels.
- Broad, shallow flow on the ATS™ results in efficient reaeration rates, which allows maintenance of near saturation dissolved oxygen levels at night.
- Low organic and ammonia loads on the system allow dissolved oxygen levels to be sustained at near or above saturation levels.
- Passage of the effluent through the microscreen provides turbulence for release of oxygen during periods of super saturation.

Table 2-14: Monthly Influent, Effluent and air temperatures, average, maximum, minimum and standard deviation for the period January 27, 2003 through May 31, 2004.

Monitoring Period		**January**			**February**			**March**			**April**		
N = 768+/- for water temperature N = 1488+/- for air temperature	Year	Influent	Effluent	Air	Influent	Effluent	Air	Influent	Effluent	Air	Influent	Effluent	Air
Mean Temperature (°C)	2003				18.8	20.3	27.0	24.2	21.1	22.5	23.4	22.9	22.1
	2004	15.9	14.0	15.2	20.5	15.5	17.7	20.8	17.3	19.3	22.0	18.6	20.4
Maximum Temperature (°C)	2003				23.9	34.4	31.2	27.3	35.7	33.3	26.3	39.6	32.2
	2004	20.3	27.0	28.4	28.1	25.0	30.1	27.7	27.8	29.8	27.5	31.9	30.8
Minimum Temperature (°C)	2003				11.8	8.6	4.6	19.4	7.4	4.7	19.4	7.4	9.3
	2004	7.3	5.4	3.5	16.8	5.4	3.5	8.4	9.1	5.5	9.6	10.8	21.3
Standard Deviation (°C)	2003				2.5	5.9	6.7	1.4	5.3	5.1	1.6	6.4	7.5
	2004	1.9	4.5	10.3	1.9	4.0	9.9	2.4	3.9	9.1	2.7	4.9	9.9

Monitoring Period		May			June			July		
N = 768 +/- for water temperature N = 1488 +/- for air temperature	Year	Influent	Effluent	Air	Influent	Effluent	Air	Influent	Effluent	Air
Mean Temperature (°C)	2003	27.3	27.1	25.1	28.3	27.1	26.2	29.9	28.3	26.7
	2004	25.8	22.2	24.1						
Maximum Temperature (°C)	2003	30.0	40.1	34.1	30.6	40.3	33.0	34.5	40.7	34.4
	2004	29.6	34.1	34.8						
Minimum Temperature (°C)	2003	25.2	18.5	18.6	27.0	20.7	19.8	28.3	22.1	20.4
	2004	22.8	15.6	13.0						
Standard Deviation (°C)	2003	1.06	5.54	3.60	0.63	4.65	3.00	1.09	5.08	3.5
	2004	1.4	4.3	8.7						

Monitoring Period		November			December		
N = 768 +/- for water temperature N = 1488 +/- for air temperature	Year	Influent	Effluent	Air	Influent	Effluent	Air
Mean Temperature (°C)	2003	21.3	20.0	19.4	15.5	14.8	15.4
Maximum Temperature (°C)	2003	26.4	30.6	29.8	29.6	24.7	26.7
Minimum Temperature (°C)	2003	13.7	9.4	5.5	6.0	5.4	1.4
Standard Deviation (°C)	2003	1.9	3.8	9.3	2.8	3.6	10.2

Because of the high surface area exposure on the ATS™ reaeration permits sustenance of relatively high dissolved oxygen levels during the night time respiration cycle, thereby eliminating the "DO sag" that is typically seen in highly productive algae communities, and which can be problematic in lake systems in Florida.

Noted within Figures 2-28 through 2-29 are the dissolved oxygen trends characteristic of the system. Included in Appendix 5 are the Sigma 900 automatic sampler graphical outputs for POR influent and effluent.

Field-testing for dissolved oxygen at the stations noted earlier provides indication of the internal oxygen dynamics, as shown within Figure 2-30. It is noteworthy that the daytime dissolved oxygen concentrations within the ATS ™ effluent prior to the microscreen provide clear indication of super saturation, with afternoon levels at times exceeding 10 mg/l. The oxygen dynamics associated with the system are discussed further within the section entitled "Impacts Upon Dissolved Oxygen Concentrations".

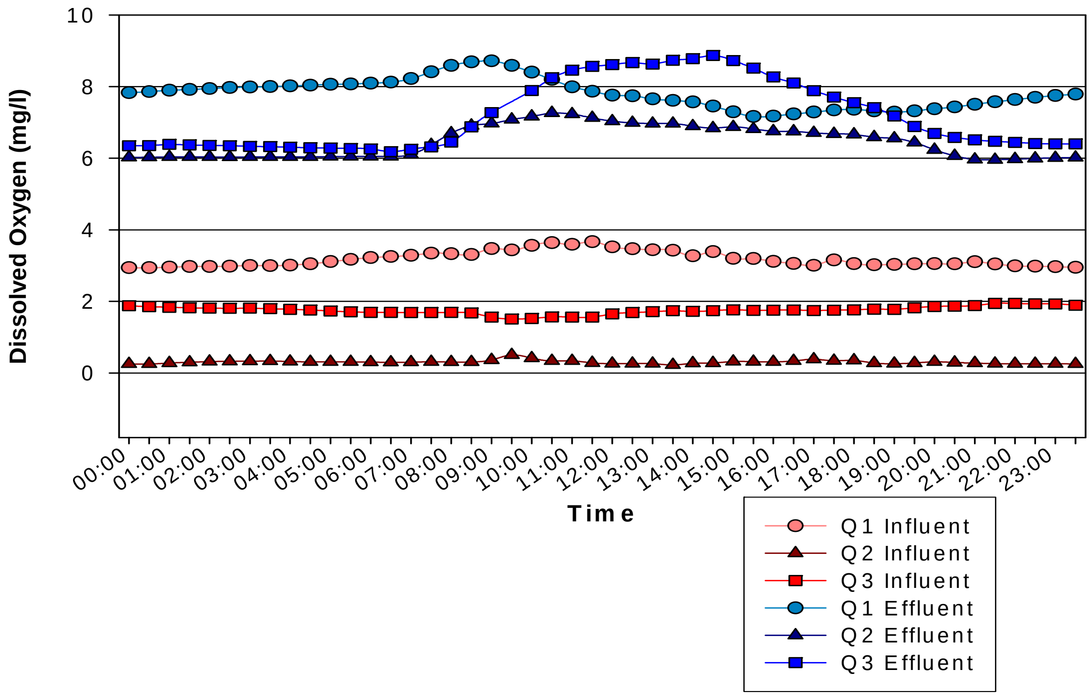


Figure 2-28: Influent and effluent mean diurnal dissolved oxygen for Quarters 1 through 3, representing the period January 27, 2003 through November 3, 2003.

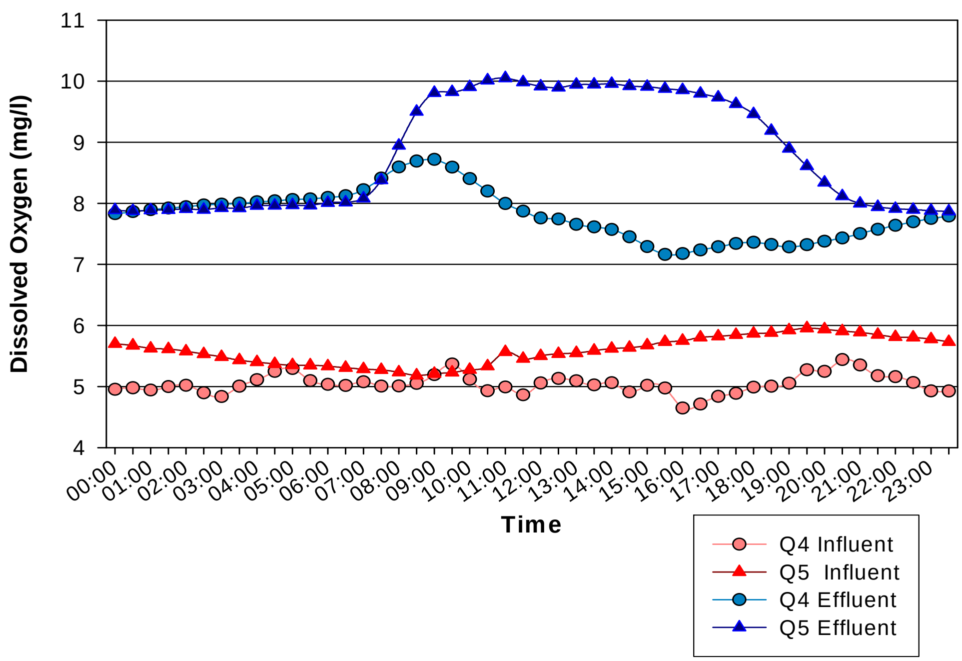


Figure 2-29: Influent and effluent mean diurnal dissolved oxygen for Quarters 4 and 5, representing the period November 3, 2003 through May 31, 2004

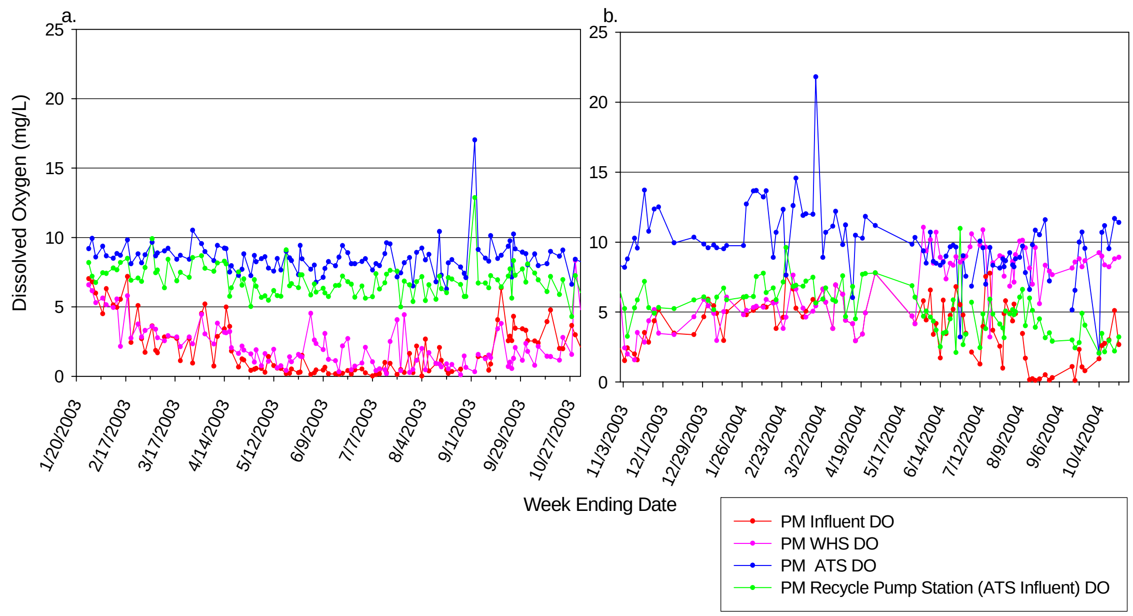


Figure 2-30: Comparative trends field sampling stations afternoon dissolved oxygen concentrations for the period January 27, 2003 through October 18, 2004. Figure (a.) represents Quarters 1-3, concentration reduction; Figure (b.) represents Quarters 4-6, load reduction study.

Calcium, Iron and Magnesium and Essential Trace Elements

To optimize treatment performance within the WHS™ - ATS™ systems, the maintenance of the highest practical biomass production capabilities is essential, as direct plant uptake of targeted pollutants—in the present case phosphorus—is the principal removal mechanism.

Optimization therefore requires (i) necessary factors for biomass productivity be sustained at required levels for vigorous growth and (ii) that the only elemental deficiency that develops is associated with the target pollutant(s). Sufficiency is thereby defined as the optimal elemental ranges to assure vigorous growth.

It is the operational intent of the system developed for the S-154 Pilot Facility to drive the system toward a phosphorus deficient condition, and that sizing and supplementations be designed such that this deficiency occurs at or near the point of effluent release—or with this system, at or near the ATS™ effluent flume. The WHS™-ATS™ optimization program, in addition to a dependence upon consistent harvesting of excessive biomass production, also relies upon supplementation of necessary elements. These elements include not only the macronutrients of carbon, phosphorus, nitrogen, potassium, calcium, magnesium and iron, but also micronutrients such as, but not limited to, manganese, zinc, copper, and boron.

Establishing a viable supplementation program requires an understanding of the behavior of the targeted plant species. For water hyacinths, considerable practical experience has been gained with nutrient supplementation, although additional work in establishing sufficiency levels will further support optimization of WHS™ treatment performance. Less information is available for cultivated periphytic algae.

To set a benchmark for initial assessment of potential deficiencies, HydroMentia staff worked with Dr. J. Benton Jones, a private consultant specializing in hydroponics cultivation, previously with the University of Georgia. Dr. Jones presently resides in Anderson, South Carolina, and works closely with Clemson University. Through Dr. Jones, and review of available literature, sufficiency levels, to be used for comparative purposes both for water and plant tissue, were established. These sufficiency concentrations, along with the L-62 water quality and early tissue analyses conducted by Dr. Jones are noted in Table 2-15.

Table 2-15: Mineral content and sufficiency ranges for water and plant tissue at system start-up of the S-154 ATS™-WHS™ Pilot Water Treatment Facility

Parameter \ Media	Water – Sufficiency Ranges	Water – L-62 Mean	Water – Effluent @ Start-up	Plant Tissue-Sufficiency Ranges	Water Hyacinth Tissue @ Start-up
Calcium	0.20-40 mg/l	35 mg/l	28 mg/l	1.9 – 2.5%	1.65 -1.74%
Magnesium	0.20-9 mg/l	17 mg/l	12 mg/l	0.35 – 0.50%	0.35 -0.37%
Iron	1-10mg/l	1.61 mg/l	0.27 mg/l	50 - 150 ppm	66 -73 ppm
Potassium	1- 4 mg/l	9 mg/l	15 mg/l	2.0 -3.0%	2.7 -2.8%
Manganese	0.55 -2.31 mg/l	10 mg/l	1 mg/l	30 -100 ppm	38 - 59 ppm
Sulfur	20-60 ppb	30,299 ppb	14,000 ppb	0.25 -0.50%	0.16 -0.59%
Copper	1.3-20 ppb	BDL	BDL	5 -15 ppm	2.2 -3.9 ppm
Zinc	3.25-16 ppb	31 ppb	37 ppb	20 -40 ppm	24 -27 ppm
Boron	100 -500 ppb	81 ppb	60 ppb	10 -30 ppm	8-23 ppm

Based upon the review of early data, deficiencies would not appear to be problematic, with copper and boron being marginal in the L-62 source water and the effluent, with iron also being indicated as below sufficiency in the effluent. Within the early hyacinth tissue (young leaves), calcium, sulfur, copper and boron appear below sufficiency with magnesium at marginally sufficient levels. As the hyacinth biomass began to develop, the algal biomass began to show indications of deficiencies, and these appeared associated with high pH, which tends to render trace minerals as well as carbon less available for plant utilization. Consequently, a supplementation program was developed. This program and its impacts are discussed in detail within Section 4—Biomass Management.

Metals

In accordance with the monitoring plan, a series of metals as noted in Table 2-16 were analyzed monthly on influent and effluent samples.

Table 2-16: Monthly influent and effluent metal concentrations for the period December 23, 2002 through November 3, 2003

Parameter	Start-up (12/23/02)		02/03/03		03/03/03		04/07/03		05/05/03	
	Inf	Eff	Inf	Eff	Inf	Eff	Inf	Eff	Inf	Eff
Boron (ppb)	87	-	47	60	77	45	62	59	96	58
Copper (ppb)	4.6	-	4.7	BDL	1.5	4.9	2.2	BDL	7.3	6.5
Manganese (ppb)	4.7	-	-	-	20.0	-	83	9.1	82	130
Potassium (mg/l)	10.0	-	10.0	15.0	13.0	12.0	11.0	16.0	13.0	14.0
Selenium (ppb)	BDL	-	6.8	4.6	6.5	5.5	BDL	BDL	BDL	BDL
Sodium (mg/l)	140	-	57	71	98	56	81	91	150	88
Sulfur (mg/l)	24	-	13	14	20	12	15	21	22	20
Zinc (ppb)	140	-	68	37	26	67	20	35	130	26

Parameter	06/3/03		07/07/03		08/11/03		9/11/03		10/11/03	
	Inf	Eff	Inf	Eff	Inf	Eff	Inf	Eff	Inf	Eff
Boron (ppb)	BDL	81	BDL	85	75	61	0.1	0	45	37
Copper (ppb)	BDL	3.5	BDL	13	1.9	5.8	4.71	11.00	BDL	5
Manganese (ppb)	49	18	67	43	-	-	44	29	27	40
Potassium (mg/l)	11.0	12.0	7.9	25.0	7.1	14.0	10.0	11.0	8.7	8.0
Selenium (ppb)	12	4.7	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Sodium (mg/l)	130	120	110	130	100	130	37	64	33	40
Sulfur (mg/l)	40.0	29.0	19.0	24.0	15.0	21.0	5.0	7.0	4.5	6.2
Zinc (ppb)	29	29	33	75	25	28	23	23	18	40

Pesticides and Herbicides

The ATS™-WHS™ system influent and effluent were tested at start-up and quarterly for organochlorides (8081) and organophosphorus (8041) type pesticides through Q3. The test results are included in Appendix 6.

Concentrations of all parameters for the start-up and Q1, Q2 and Q3 influent and effluent samples were shown to below detection limits, with the exception of the parameters 4,4'-DDD and 4,4'-DDT in the Q1 influent sample collected on December 16, 2002 which had concentrations of 0.19 mg/l and 1.1 mg/l, respectively. These data were reported to District staff.

In conjunction with spraying of herbicides within the L-62 canal as part of the District's routine vegetation management program, testing was conducted for select herbicides prior to pumping L-62 waters into the WHS™- ATS™ treatment system. Results from these analyses are also included in Appendix 6. Samples collected on September 2, 2003 were analyzed via methods 8151 and 549.2, and no detectable levels of herbicides were observed.

PHOSPHORUS REDUCTION

Total Phosphorus

Outflow Concentration Optimization Period

During Q1, the system received from a total flow of 41.27 million gallons from the L-62 canal 190.17 pounds of total phosphorus, with weekly loads ranging from 6.06 to 22.50 pounds. Total phosphorus discharged with the system effluent was 25.29 pounds, with the weekly load ranging from 0.85 to 4.02 pounds, associated with a total flow 37.60 million gallons.The weekly concentration of influent total phosphorus ranged from 418 ppb to 748 ppb, with a flow weighted mean of 552 ppb. The weekly concentration of effluent total phosphorus ranged from 43 to 139 ppb, with a flow weighted mean of 80 ppb. The percent removal for total phosphorus for Q1 averaged 86.8%, ranging from 70.6 to 95.5%.

During Q2, the system received from a total flow of 40.92 million gallons from the L-62 canal, 148.7 pounds of total phosphorus, with weekly loads ranging from 4.81 to 18.91 pounds. Total phosphorus discharged with the system effluent was 24.87 pounds, with the weekly load ranging from 0.51 to 6.02 pounds, associated with a total flow of 39.10 million gallons.The weekly concentration of influent total phosphorus ranged from 194 ppb to 770 ppb, with a flow weighted mean of 436 ppb. The weekly concentration of effluent total phosphorus ranged from 30 to 200 ppb, with a flow weighted mean of 79 ppb. The percent removal for total phosphorus for Q2 averaged 83.3%, ranging from 33.6 to 96.9%. Note that lower removal rates for this quarter are associated with the disruptive event previously discussed within this section.

During Q3, the system received from a total flow of 35.28 million gallons from the L-62 canal, 127.8 pounds of total phosphorus, with weekly loads ranging from 5.95 to 14.87 pounds. Total phosphorus discharged with the system effluent was 24.72 pounds, with the weekly load ranging from 0.85 to 3.16 pounds, associated with a total flow 36.31 million gallons.The weekly concentration of influent total phosphorus ranged from 293 ppb to 690 ppb, with a flow weighted mean of 434 ppb. The weekly concentration of effluent total phosphorus ranged from 52 to 158 ppb, with a flow weighted mean of 82 ppb. The percent removal for total phosphorus for Q3 averaged 80.7%, ranging from 65.4 to 89.7%.

For the combined Q1+Q2+Q3 period, the system received a total flow of 117.47 million gallons from the L-62 canal and 466.71 pounds of total phosphorus, with weekly loads ranging from 4.81 to 22.50 pounds. Total phosphorus discharged with the system effluent was 74.88 pounds, with the weekly load ranging from 0.51 to 6.02 pounds, associated with a total flow of 113.01 million gallons.The weekly concentration of influent total phosphorus ranged from 194 ppb to 770 ppb, with a flow weighted mean of 476 ppb. The weekly concentration of effluent total phosphorus ranged from 30 to 200 ppb, with a flow weighted mean of 79 ppb. The system achieved effluent TP concentration of less than 40 ppb in greater than 10% of samples during these quarters. The comparative weekly total phosphorus concentrations are noted in Table 2-8 as previously presented. The combined Q1+Q2+Q3 removal for total phosphorus was 83.7% concentration reduction.

Load Reduction Optimization Period

During Q4 and through Q6 operational changes were enacted to allow an increase of areal loading rate in terms of both hydraulic loading and phosphorus loading, thereby providing a wider view of system performance as applied to the specific water quality conditions associated with LOW and S-154—i.e. low alkalinity, low hardness, low N:P ratio. The chronology of process area changes and hydraulic loading rate, as well as total phosphorus removal rates are noted in Table 2-17. Included also is the linear hydraulic loading rate (LHLR) across the ATS™, which is the influent flow in average gpm divided by the entire width in feet of the ATS™. This parameter is related to the velocity across the ATS™, and hence an indicator of turbidity and boundary layer disruption. This is a parameter that has been shown to be important to algae production and phosphorus removal rates. This importance is discussed in greater detail within the "-154 Single Stage Algal Turf Scrubber® (ATS™) Final Report".

During Q4, the treatment system received 89.8 pounds of total phosphorus from the L-62 canal, with weekly loads ranging from 4.51 to 12.7 pounds. Total phosphorus discharged with the system effluent was 42.9 pounds, with the weekly load ranging from 2.51 to 4.73 pounds. Note that influent TP concentrations were lower during Q4 than in previous quarters, resulting in only slightly higher phosphorus load for this quarter. The weekly concentration of influent total phosphorus ranged from 102 ppb to 294 ppb, with a flow weighted mean of 160 ppb. The weekly concentration of effluent total phosphorus ranged from 52 to 120 ppb, with a flow weighted mean of 76 ppb. The percent removal for total phosphorus for Q4 averaged 55.1%, ranging from 31.5 to 77.9%.

During Q5, the system received from the L-62 canal, 219.3 pounds of total phosphorus, with weekly loads ranging from 5.68 to 30.56 pounds. Total phosphorus discharged with the system effluent was 96.08 pounds, with the weekly load ranging from 3.04 to 10.24 pounds, associated with a total flow 99.6 million gallons.The weekly concentration of influent total phosphorus ranged from 116 ppb to 596 ppb, with a flow weighted mean of 266 ppb. The weekly concentration of effluent total phosphorus ranged from 65.8 to 231 ppb, with a flow weighted mean of 118 ppb. The percent removal for total phosphorus for Q5 averaged 59.6%, ranging from 32.7 to 75.3% (Figure 2-37)

During Q6, the system received 191.3 pounds of total phosphorus from the L-62 canal, with weekly loads ranging from 2.85 to 51.61 pounds. Total phosphorus discharged with the system effluent was 109.6 pounds, with the weekly load ranging from 0.91 to 45.57 pounds.The weekly concentration of influent total phosphorus ranged from 70 ppb to 1,080 ppb, with a flow weighted mean of 371 ppb. The weekly concentration of effluent total phosphorus ranged from 38 ppb to 1,080 ppm, with a flow weighted mean of 277 ppb. It should be noted that median influent and effluent total phosphorus concentrations were 157 ppb and 61 ppb, respectively. Both influent and effluent TP concentrations increased following two hurricanes during this quarter. Mean total phosphorus removal was 39% overall for Q6, but average load removal was 55% prior to the storms and only 4% after.

For Q4 through Q6, the system received a total flow of 266.1 million gallons from the L-62 canal, and 500.36 pounds of total phosphorus, with weekly loads ranging from2.85 to 51.61 pounds. Total phosphorus discharged with system effluent was 248.54 pounds, with the weekly load ranging from 0.91 pounds to 48 pounds, associated with a total flow of 251.8 million gallons. The weekly concentration of influent total phosphorus ranged from 71 ppb to 1,080 ppb, with a flow weighted mean of 279 ppb. The weekly concentration of effluent total phosphorus ranged from 38 to 1,080 ppm with a flow weighted mean of 167 ppb. The percent removal for Q6 averaged 39.5% ranging from –48.4 to 78%. The combined Q4+Q6 average removal for total phosphorus was 46.8% load reduction.

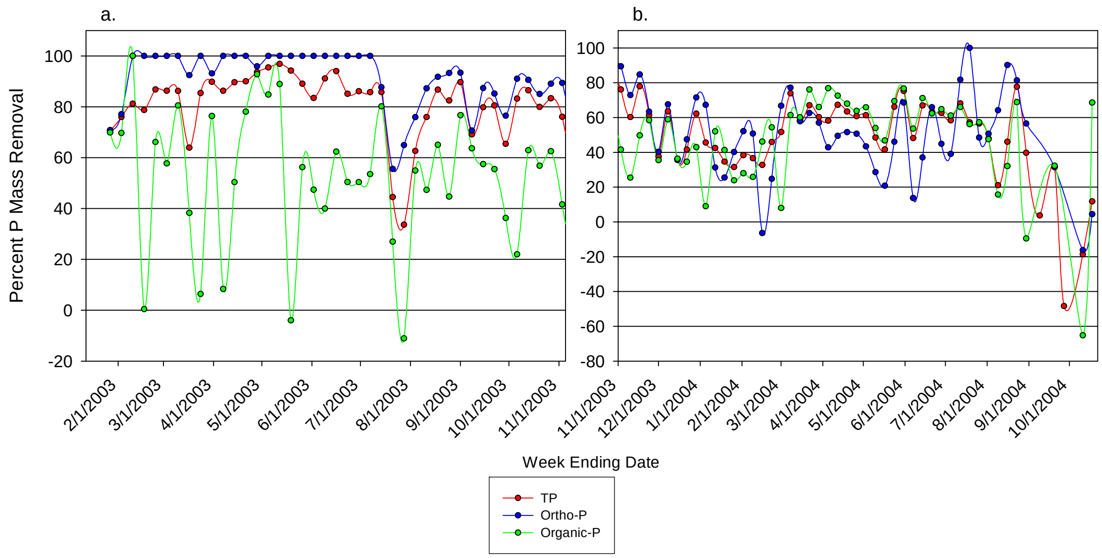


Figure 2-31: Percent removal rates for total, ortho and organic phosphorus for the period January 27, 2003 through October 18, 2004. Figure (a.) represents Quarters 1-3, concentration reduction optimization; Figure (b.) represents Quarters 4-6, load reduction optimization.

Ortho Phosphorus

Outflow Concentration Optimization Period

For Q1, the ortho phosphorus influent load (PO_4^{-3} -P), which is the soluble fraction, and that most accessible to biological systems, was 127.46 pounds or 67% of the total phosphorus, with weekly loads ranging from 4.19 to 17.80 pounds. The weekly concentration of influent ortho phosphorus ranged from 182 ppb to 593 ppb, with a flow weighted mean of 370 ppb. The ortho phosphorus discharged with the system effluent was 3.08 pounds, with the weekly load ranging from 0 to 1.27 pounds. The weekly concentration of effluent ortho phosphorus ranged from 0 to 100 ppb, with a flow weighted mean of 10 ppb. The percent removal for ortho phosphorus averaged 97.6%, ranging from 77.1 to 100%.

For Q2, the ortho phosphorus influent load (PO_4^{-3} -P) was 110.25 pounds or 74% of the total phosphorus, with weekly loads ranging from 1.78 to 17.86 pounds. The weekly concentration of influent ortho phosphorus ranged from 72 ppb to 714 ppb, with a flow weighted mean of 323 ppb. The ortho phosphorus discharged with the system effluent was 6.35 pounds, with the weekly load ranging from 0 to 2.95 pounds. The weekly concentration of effluent ortho phosphorus ranged from 0 to 98 ppb, with a flow weighted mean of 20 ppb. The comparative weekly ortho phosphorus concentrations are noted in Table 2-8 as previously presented. The percent removal for ortho phosphorus averaged 94.2%, ranging from 55.5 to 100%.

For Q3, the ortho phosphorus influent load (PO_4^{-3} -P) was 101.37 pounds or 79% of the total phosphorus, with weekly loads ranging from 4.31 to 12.53 pounds. The weekly concentration of influent ortho phosphorus ranged from 210 ppb to 543 ppb, with a flow weighted mean of 345 ppb. The ortho phosphorus discharged with the system effluent was 12.61 pounds, with the weekly load ranging from 0.43 to 2.37 pounds. The weekly concentration of effluent ortho phosphorus ranged from 23 to 119 ppb, with a flow weighted mean of 42 ppb. The comparative weekly ortho phosphorus concentrations are noted in Table 2-8 as previously presented. The percent removal for ortho phosphorus averaged 88%, ranging from 71 to 94 %.

For the combined Q1+Q2+Q3 period, the ortho phosphorus influent load (PO_4^{-3} -P), was 339.08

pounds or 72.7% of the total phosphorus, with weekly loads ranging from 1.78 to 17.86 pounds. The weekly concentration of influent ortho phosphorus ranged from 72 ppb to 714 ppb, with a flow weighted mean of 346 ppb. The ortho phosphorus discharged with the system effluent was 22.04 pounds, with the weekly load ranging from 0 to 2.95 pounds. The weekly concentration of effluent ortho phosphorus ranged from 0 to 119 ppb, with a flow weighted mean of 23 ppb. The comparative weekly ortho phosphorus concentrations are noted in Table 2-8 as previously presented. The combined percent removal for ortho phosphorus for the Q1+Q2+Q3 period averaged 93.5%, ranging from 55.5 to 100%.

Load Reduction Optimization Period

For Q4, the ortho phosphorus influent load (PO_4^{-3} -P) was 50.39 pounds or 59.42% of the total phosphorus, with weekly loads ranging from 2.15 to 9.95 pounds. The weekly concentration of influent ortho phosphorus ranged from 43 ppb to 237 ppb, with a flow weighted mean of 96 ppb. The ortho phosphorus discharged with the system effluent was 18.81 pounds, with the weekly load ranging from 1.18 to 2.76 pounds. The weekly concentration of effluent ortho phosphorus ranged from 24 to 60 ppb, with a flow weighted mean of 36 ppb. The comparative weekly ortho phosphorus concentrations are noted in Table 2-8 as previously presented. The percent removal for ortho phosphorus averaged 62.7%, ranging from 25.5 to 84.7 %.

For Q5, the ortho phosphorus influent load (PO_4^{-3} -P) was 106.19 pounds or 42.8% of the total phosphorus, with weekly loads ranging from 1.55 to 20.80 pounds. The weekly concentration of influent ortho phosphorus ranged from 29 ppb to 399 ppb, with a flow weighted mean of 109 ppb. The ortho phosphorus discharged with the system effluent was 50.00 pounds, with the weekly load ranging from 0.86 to 7.79 pounds. The weekly concentration of effluent ortho phosphorus ranged from 18 to 176 ppb, with a flow weighted mean of 55 ppb. The comparative weekly ortho phosphorus concentrations are noted in Table 2-8 as previously presented. The percent removal for ortho phosphorus averaged 52.9%, ranging from –6.47 to 77.1 %.

For Q6, the ortho phosphorus influent load (PO_4^{-3} -P) was 142.27 pounds or 58.2% of the total phosphorus, with weekly loads ranging from 0.09 to 45.73 pounds. The weekly concentration of influent ortho phosphorus ranged from 4 ppb to 1,040 ppb, with a flow weighted mean of 236 ppb. The ortho phosphorus discharged with the system effluent was 115.04 pounds, with the weekly load ranging from 0.0 to 45.7 pounds. The weekly concentration of effluent ortho phosphorus ranged from below detectable limits to 1,000 ppb, with a flow weighted mean of 178 ppb. The percent removal for ortho phosphorus averaged 49.6%, ranging from –16.28 to 100 %.

For the combined Q4-Q6 period, the ortho phosphorus influent load (PO_4^{-3}-P), was 308.73 pounds or 52.4% of the total phosphorus, with weekly loads ranging from 0.09 to 45.73 pounds. The weekly concentration of influent ortho phosphorus ranged from 0 ppb to 1,040 ppb, with a flow weighted mean of 154 ppb. The ortho phosphorus discharged with the system effluent was 180 pounds, with the weekly load ranging from below detectable limits (0.00 pounds) to 45.73 pounds. The weekly concentration of effluent ortho phosphorus ranged from below detectable limits to 1,090 ppm, with a flow weighted mean of 94 ppb. The comparative weekly ortho phosphorus concentrations are noted in Table 2-8 as previously presented. The combined percent removal for ortho phosphorus for Q4-Q6 averaged 68.62%, ranging from –16.28 to 100%.

Organic Phosphorus

Outflow Concentration Optimization Period

Organic phosphorus, which is that fraction calculated as the difference between total and ortho phosphorus, represents phosphorus bound to organic compounds. The nature of the compound and the type of bonding varies considerably. Consequently the extent to which organic phosphorus is available to biological components also varies.

For Q1 the organic phosphorus influent load was 62.71 pounds or 33% of the total phosphorus, with weekly loads ranging from 0 to 11.83 pounds. The weekly concentration of influent organic phosphorus ranged from 0 ppb to 492 ppb, with a flow weighted mean of 182 ppb. The organic phosphorus discharged with the system effluent was 22.21 pounds, with the weekly load ranging from 0.85 to 3.60 pounds. The weekly concentration of effluent organic phosphorus ranged from 17 to 125 ppb, with a mean of 70 ppb. The percent removal for organic phosphorus averaged 64.6%, ranging from 0 to 92.8%,

For Q2 the organic phosphorus influent load was 38.45 pounds or 26% of the total phosphorus, with weekly loads ranging from 1.05 to 4.83 pounds. The weekly concentration of influent organic phosphorus ranged from 42 ppb to 220 ppb, with a flow weighted mean of 113 ppb. The organic phosphorus discharged with the system effluent was 18.52 pounds, with the weekly load ranging from 0.51 to 3.06 pounds. The weekly concentration of effluent organic phosphorus ranged from 30 to 102 ppb, with a mean of 59 ppb. The percent removal for organic phosphorus averaged 51.8 %, ranging from –11.0 to 89.0%.

For Q3 the organic phosphorus influent load was 26.43 pounds or 21% of the total phosphorus, with weekly loads ranging from 0.90 to 3.32 pounds. The weekly concentration of influent organic phosphorus ranged from 81 ppb to 148 ppb, with a flow weighted mean of 90 ppb. The organic phosphorus discharged with the system effluent was 12.11 pounds, with the weekly load ranging from 0.43 to 1.37 pounds. The weekly concentration of effluent organic phosphorus ranged from 25 to 66 ppb, with a mean of 40 ppb. The percent removal for organic phosphorus averaged 54.2 %, ranging from 22.0 to 76.7%.

For the combined Q1+Q2+Q3 the organic phosphorus influent load was 127.59 pounds or 27% of the total phosphorus, with weekly loads ranging from 0 to 11.83 pounds. The weekly concentration of influent organic phosphorus ranged from 0 ppb to 492 ppb, with a flow weighted mean of 130 ppb. The organic phosphorus discharged with the system effluent was 52.83 pounds, with the weekly load ranging from 0.43 to 3.60 pounds. The weekly concentration of effluent organic phosphorus ranged from 17 to 125 ppb, with a mean of 55 ppb. The percent removal for organic phosphorus for this period averaged 58.6%, ranging from –11.0 to 89.0%.

Table 2-17: Summary of process area, hydraulic loading and phosphorus loading and removal rates during Q4-Q6.

Week Ending	ATS Area (m2)	WHS Area (m2)	Total process area (m2)	ATS Width (ft)	Average Weekly Flow (MG)	HLR (cm/d)	LHLR (gpm/lf)	Influent TP (lbs)	Effluent TP (lbs)	Total System TP loading rate (g/m^2/yr)	Total System TP removal rate (g/m2/yr)
11/10/03	3,616	10,120	13,736	130	3.50	13.78	2.68	8.48	3.37	14.57	8.77
11/17/03	3,616	10,120	13,736	130	4.50	17.70	3.44	12.33	2.72	21.20	16.52
11/24/03	3,616	10,120	13,736	130	6.49	25.53	4.96	12.68	4.90	21.80	13.38
12/1/03	3,616	10,120	13,736	130	6.28	24.72	4.80	5.98	3.74	10.28	3.86
12/8/03	3,616	10,120	13,736	130	6.18	24.33	4.73	6.87	2.51	11.80	7.49
12/15/03	3,616	10,120	13,736	130	6.28	24.71	4.80	5.22	3.48	8.97	2.99
12/22/03	3,616	10,120	13,736	130	5.15	20.26	3.94	4.51	2.63	7.75	3.22
12/29/03	3,616	10,120	13,736	130	5.83	22.94	4.46	6.55	2.64	11.26	6.73
1/5/04	3,616	5,060	8,676	130	6.93	43.18	5.30	7.75	4.23	21.09	9.59
1/12/04	3,616	5,060	8,676	130	5.98	37.25	4.57	6.62	4.01	18.07	7.13
1/19/04	3,616	5,060	8,676	130	6.07	37.83	4.64	7.23	4.74	19.73	6.78
1/26/04	3,616	5,060	8,676	130	6.11	38.10	4.68	5.59	3.99	15.26	4.37
2/2/04	3,616	5,060	8,676	130	6.07	37.86	4.65	6.93	4.30	18.90	7.17
2/9/04	3,616	5,060	8,676	130	6.39	39.86	4.89	7.06	4.64	19.26	6.61
2/16/04	3,616	5,060	8,676	130	6.30	39.27	4.82	5.88	4.13	16.03	4.78
2/23/04	3,616	5,060	8,676	130	6.89	42.95	5.27	7.18	4.03	19.59	8.60
3/1/04	3,616	5,060	8,676	130	6.33	39.45	4.84	7.36	3.68	20.08	10.04
3/8/04	3,616	5,060	8,676	130	6.19	38.55	4.73	20.15	5.55	54.98	39.84
3/15/04	3,416	5,060	8,476	123	5.86	37.38	4.74	19.19	8.35	53.61	30.28
3/22/04	3,416	5,060	8,476	123	6.09	38.86	4.93	30.07	11.82	83.97	50.97
3/29/04	3,416	5,060	8,476	123	6.03	38.45	4.88	22.36	9.24	62.45	36.65
4/5/04	3,416	5,060	8,476	123	5.68	36.22	4.60	15.27	6.62	42.64	24.15
4/12/04	3,416	5,060	8,476	123	3.11	19.84	2.52	9.79	3.42	27.34	17.79
4/19/04	3,416	5,060	8,476	123	5.86	37.41	4.75	14.30	5.52	39.95	24.54
4/26/04	3,416	5,060	8,476	123	5.75	36.69	4.66	10.92	4.51	30.49	17.90
5/3/04	3,416	5,060	8,476	123	5.36	34.20	4.34	10.56	4.26	29.48	17.59
5/10/04	1,501	5,060	6,561	54	5.56	45.84	10.25	8.79	4.78	31.70	14.47
5/17/04	1,501	5,060	6,561	54	5.99	49.35	11.03	10.97	6.77	39.60	15.19
5/24/04	3,030	5,060	8,090	109	6.04	40.39	5.52	12.51	4.41	36.62	23.70
5/31/04	3,030	5,060	8,090	109	6.04	40.39	5.52	16.07	4.11	47.01	35.00
6/7/04	3,030	5,060	8,090	109	5.20	34.75	4.75	9.14	4.63	26.76	13.21
6/14/04	3,030	5,060	8,090	109	6.69	44.72	6.11	9.80	3.19	28.67	19.33
6/21/04	3,030	5,060	8,090	109	5.94	39.67	5.42	7.77	2.84	22.74	14.42
6/28/04	1,021	5,060	6,081	37	5.56	49.44	15.06	5.42	1.99	21.11	13.35
7/5/04	1,021	5,060	6,081	37	5.52	49.04	14.94	4.08	1.67	15.87	9.38
7/12/04	1,021	5,060	6,081	37	3.24	50.34	15.34	2.98	0.91	20.30	14.12
7/19/04	1,021	5,060	6,081	37	5.61	49.85	15.18	4.23	1.77	16.45	9.55
7/26/04	1,021	5,060	6,081	37	5.82	51.72	15.75	4.44	1.89	17.27	9.93
8/2/04	1,021	5,060	6,081	37	5.65	50.25	15.31	3.83	1.96	14.91	7.30
8/9/04	1,021	5,060	6,081	37	5.70	50.69	15.44	3.39	2.62	13.21	3.00
8/16/04	1,021	5,060	6,081	37	3.61	32.06	9.77	2.96	1.54	11.51	5.49
8/23/04	1,021	5,060	6,081	37	5.15	45.76	13.94	18.04	3.96	70.22	54.79
8/30/04	1,021	5,060	6,081	37	4.57	40.60	12.37	33.13	19.43	128.96	53.34
9/20/04	1,021	5,060	6,081	37	2.23	46.27	14.10	18.47	11.62	167.74	62.19
10/18/04	1,021	5,060	6,081	37	5.76	51.18	15.59	52.52	45.70	204.46	26.54

Load Reduction Optimization Period

For Q4 the organic phosphorus influent load was 34.80 pounds or 40.8% of the total phosphorus, with weekly loads ranging from 2.05 to 5.14 pounds. The weekly concentration of influent organic phosphorus ranged from 46 ppb to 90 ppb, with a flow weighted mean of 65 ppb. The organic phosphorus discharged with the system effluent was 20.12 pounds, with the weekly load ranging from 1.20 to 2.62 pounds. The weekly concentration of effluent organic phosphorus ranged from 26 to 60 ppb, with a mean of 40 ppb. The percent removal for organic phosphorus averaged 42.2 %, ranging from 9.0 to 58.9%.

For Q5 the organic phosphorus influent load was 125.28 pounds or 52.2% of the total phosphorus, with weekly loads ranging from 1.91 to 13.6 pounds. The weekly concentration of influent organic phosphorus ranged from 38 ppb to 259 ppb, with a flow weighted mean of 145 ppb. The organic phosphorus discharged with the system effluent was 47.79 pounds, with the weekly load ranging from1.41 to 5.37 pounds. The weekly concentration of effluent organic phosphorus ranged from 32 to 104 ppb, with a mean of 60 ppb. The percent removal for organic phosphorus averaged 46.9 %, ranging from –6.5 to77.13%.

For Q6 the organic phosphorus influent load was 74.2 pounds or 30.4% of the total phosphorus, with weekly loads ranging from 1.97 to 8.42 pounds. The weekly concentration of influent organic phosphorus ranged from 39 ppb to 215 ppb, with a flow weighted mean of 107 ppb. The organic phosphorus discharged with the system effluent was 39.4 pounds, with the weekly load ranging from0.84 to8.99 pounds. The weekly concentration of effluent organic phosphorus ranged from 32 to 244. ppb, with a mean of 65 ppb. The percent removal for organic phosphorus averaged 48.7 %, ranging from -65 to 71.4%. Organic phosphorus effluent concentrations were particularly influenced in Q6 by sloughing of the algal mat for a period of about 2 weeks after the hurricanes. This will be discussed further in Section 3.

For the combined Q4-Q6 the organic phosphorus influent load was 241.45 pounds or 42.4% of total phosphorus, with weekly loads ranging from 1.91 to 13.57 pounds. The weekly concentration of influent organic phosphorus ranged from 38 ppb to 259 ppb, with a flow weighted mean of 110.5 ppb. The organic phosphorus discharged with the system effluent was 105.4 pounds, with the weekly load ranging from 0.84 to 8.99 pounds. The weekly concentration of effluent organic phosphorus ranged from 26 to 244 ppb, with a mean of 56 ppb. The combined percent removal for organic phosphorus averaged 46.1%, ranging from -65 to 77.1%.

Phosphorus Areal Removal Rates

Outflow Concentration Optimization Period

Total phosphorus areal removal rates during Q1 for the entire system; with a process area of 10,120 square meters of WHS™ and an active ATS™ area of 8,311 square meters (deducting dry areas within the floways) averaged 15.14 g-P/m^2-year, with a standard deviation of 6.87 g-P/m^2-year, as noted in Figure 2-37. Estimates were also made from the grab sample data from the WHS™. Based on these estimates, during Q1 the WHS™ provided total phosphorus removal at an average rate of 24.42 g-P/m^2-year, with the ATS™ providing total phosphorus removal at an average rate of 3.83 g-P/m^2-year.

Total phosphorus areal removal rates during Q2 for the entire system averaged 12.20 g-P/m^2-year, with a standard deviation of 6.43 g-P/m^2-year. For the non-disruptive period from 5/12/03 to 7/7/03,the entire system areal phosphorus removal rate averaged 13.61 g-P/m^2-year, with a standard deviation of 4.99 g-P/m^2-year. During Q2 the WHS™ provided total phosphorus removal at an average rate of 12.95 g-P/m^2-year for the entire period, and 16.53 g-P/m^2-year during the non-disruptive period, with the ATS™ providing total phosphorus removal at an average rate of 11.29 g-P/m^2-year and 10.06 g-P/m^2-year during the non-disruptive period. These trends are noted within Figure 2-32.

Total phosphorus areal removal rates during Q3 for the entire system averaged 10.78 g-P/m^2-year, with a standard deviation of 3.27 g-P/m^2-year. The areal loading rate was 13.36 g-P/m^2-year for the Q3 POR. As noted in Figure 2-38, during Q3 the WHS™ provided total phosphorus removal at an average rate of 13.07 g-P/m^2-year, with the ATS™ providing total phosphorus removal at an average rate of 7.98 g-P/m^2-year.

Total phosphorus areal removal rates for the combined Q1+Q2+Q3 period for the entire system averaged 12.76 g-P/m^2-year, with a standard deviation of 6.00 g-P/m^2-year, with a total phosphorus-loading rate of 15.20 g-P/m^2-year. For the combined period the WHS™ provided total phosphorus removal at an average rate of 16.87 g-P/m^2-year, with the ATS™ providing total phosphorus removal at an average rate of 7.76 g-P/m^2-yr.

Load Reduction Optimization Period

Total phosphorus areal removal rates during Q4 for the system averaged 7.57 g-P/m^2-year, with a standard deviation of 4.1 g-P/m^2-year. The areal loading rate was 15.00 g-P/m^2-year. Influent total phosphorus concentrations during this quarter were comparatively low, therefore there was not an increase in loading rates, even though process surface area was reduced and hydraulic loading increased, as shown in Table 2-17. Estimates were also made during Q4 from the grab sample data from the WHS™. Based on these estimates, the WHS™ provided total phosphorus removal at an average rate of 5.44 g-P/m^2-year, with the ATS™ providing total phosphorus removal at an average rate of 12.79 g-P/m^2-year.

During Q5, average areal TP removal rate for the system was 20.88 g-P/m^2-year with a standard deviation of 13.09 g-P/m^2-year. The TP loading rate for this quarter was 36.32 g-P/m^2-year. Estimates from the WHS™ grab samples indicate removal rates of 26.36 g-P/m^2-year with the ATS™ providing TP removal at a rate of 12.58 g-P/m^2-year.

During Q6, average areal TP removal rate for the system was 19.3 g-P/m^2-year with a standard deviation of 17.0 g-P/m^2-year. The system TP loading rate for this quarter was 50.22 g-P/m^2-year. Estimates from the WHS™ grab samples indicate removal rates of 15.16 g-P/m^2-year with the ATS™ providing TP removal at a rate of 40.38 g-P/m^2-year.

For Q4-Q6, the influent TP loading rate to the system averaged 35.75 g-P/m^2-year, with removal of 17.05 g-P/m^2-year and standard deviation 13.9 g-P/m^2-year. Grab samples showed mean WHS™

total phosphorus removal rate of 17.05 g-P/m^2-year and ATS™ removal of 21.5 g-P/m^2-year. Of note is the reduced area of the ATS™ making its contribution to total process area less than 17%. Improvement of the ATS™ areal phosphorus removal rates for this time period is not evident in analysis of the two stage system, however when comparing ATS™ performance on an areal basis diurng these quarters relative to the first three quarters, there is clear indication that hydraulic loading rate plays an important role in the efficiency of this technology as a load reduction tool.

General Discussion

The system-projected performance as presented within the Preliminary Engineering report was a total phosphorus reduction rate of 17.77 g-P/m^2-year, from a loading rate of 19.11 g-P/m^2-year, with the WHS™ providing 23.74 g-P/m^2-year and the ATS™ providing 11.79 g-P/m^2-year. Noted within Figure 2-33 is a comparison of the loading versus removal rates for each quarter. Note that the correlation is much improved, and the slope steeper when the data collected immediately following the hurricanes are excluded. There is auto-correlation between loading and removal, so the high r^2 value is not unexpected. It does however reveal stability and a high level of predictability in system performance, and a capability to sustain high removal rates at higher nutrient and hydraulic loading. During Q4 through Q6, under higher areal loading rates, data points are pushed further to the right on these graphs, while phosphorus removal rates continue to increase, maintaining a strong linear relationship and a high r^2.

A review of Figure 2-32 provides indication that the contributions of the two unit processes during the second quarter was much more equitable than the first quarter, in which removals were dominated by the WHS™, and that this trend is even more noticeable in the third quarter. The drop in performance of the WHS™ in the second quarter may well be attributable to increased crop densities and attendant reductions in productivity, as well as impacts of the disruptive event. A general recovery is noted in the third quarter, with the WHS™ and ATS™ consistently sharing in contribution to total phosphorus removal at 60:40 percent, respectively, also noted within Figures 2-34 through 2-38. Variability in treatment contributions increased under the higher loading regime, with ATS™ contribution frequently exceeding WHS™ contribution through quarter four, which was seldom seen in previous quarters. In fact, ATS™ total phosphorus removal contribution was about equal to WHS™ TP removal contribution (49.1% vs. 50.9%, respectively). The opposite is true however of Q5, where WHS™ TP removal contribution was 69.1% and ATS™ contribution was 30.9%. Toward the end of Q5, ATS™ contribution fell sharply even though overall system performance remained high. Some of this is may be attributable to the disruptions caused by construction of the individual floways associated with the contract extension. During this period, flows were intermittently diverted or shut down to the ATS™. In June the ATS™ system was reduced in area and moved to the north ATS™ unit, thereby increasing the linear hydraulic loading rate and stabilizing the operation.

The performance recovery of the ATS™ during Q3 is due largely to the return of an extensive standing crop of filamentous algae, and the nutrient contribution from the WHS™. The impact of the disruptive event is clearly noticeable within Figure 2-32. The role of crop health and production in treatment performance is discussed in further detail within Section 4 and 5.

During Q2, prior to the disruption, as with Q1, ortho phosphorus reduction was extensive, approaching 100%. The organic phosphorus removal was noted at about 50% during this same time period. During the disruptive period, ortho phosphorus removal efficiency fell from 100% to about 79%, while organic phosphorus removal efficiency fell from 50% to about 41%. Recovery was observed during Q3 to an ortho phosphorus removal of 88%, as noted in Figure 2-34. As with total phosphorus, the WHS™ and ATS™ shared removal contributions for ortho phosphorus at about 60%: 40%, respectively.

Under the increased hydraulic loading regime, ortho phosphorus removal dropped to about 55% during Q4 and Q5 and organic phosphorus removal was slightly less at 39% for Q4 and 47% for Q5. During Q6, system removal decreased to 49% and 43% for ortho and organic phosphorus, respectively. It is important to note, however that ortho-phosphorus removal was 55% and organic phosphorus removal was 59.5% during Q6 prior to the first hurricane event. For Quarters 4-6, including those data collected after the hurricanes, system TP removal was 47%, Ortho-P removal was 49%, and Organic-P removal was 46%. These values are slightly less than those observed for Q4-Q6 prior to the hurricanes. For the period November 3, 2004 through August 30, 2004, TP removal was 52.6%, ortho-P removal was 51% and organic P removal was 48.5%. During Q4, ortho phosphorus removal was 50:50 for the WHS™ and ATS™, but this trend did not continue into Q5, with WHS™ ortho phosphorus removal contribution of 81% vs. ATS™ 19% contribution. During Q6, the ATS™ outperformed the WHS™ with respect to ortho-phosphorus removal with 65% vs. 35% contribution (Figure 2-43).

The organic phosphorus fraction, as anticipated, has proven more recalcitrant than ortho phosphorus throughout all quarters, and its overall removal rate was least impacted by the disruption in July. While the development and stabilization of the hyacinth and algal biomass does result in improved removal efficiencies of organic phosphorus, ortho phosphorus is much more accessible, and hence more efficiently recovered. It is suggested that the more recalcitrant portion of the organic fraction may be biologically vulnerable only to enzymes such as alkaline phosphatase or Phospho-Diesterase (PDEase), which can be produced by certain species of bacteria and algae and physical processes such as filtration and settling that occur within the two treatment systems. Through Q1-Q3, generally the WHS™ provided the greatest removal of organic phosphorus, with two exceptions, that being the disruptive period in July, and a period in early October 2003 when the WHS™ actually was an organic phosphorus contributor. It is not clear what may have caused the event in October. Because the WHS™ and ATS™ samples are grab samples, the issue may be associated with the inherent issue of grab data reliability.

The WHS™ was less effective than the ATS™ at removing organic phosphorus during Q4, only contributing to 42% removal versus the 58% removal contribution of the ATS™. This trend continued with 79% and 21% removal contribution by the ATS™ and WHS™, respectively during Q5, and 52% and 48% removal contribution by the ATS™ and WHS™ respectively during Q6 (Figure 2-41).

Throughout the high loading rate study, the WHS™ was responsible for 65.5% of TP removal, 58% of Ortho-P removal, and 25% of Organic-P removal. Conversely, the ATS™ contributed to 34.5% of TP removal, 41% of Ortho-P removal, and 75% of Organic-P removal. This offers some further indication of active enzyme activity on the ATS™.

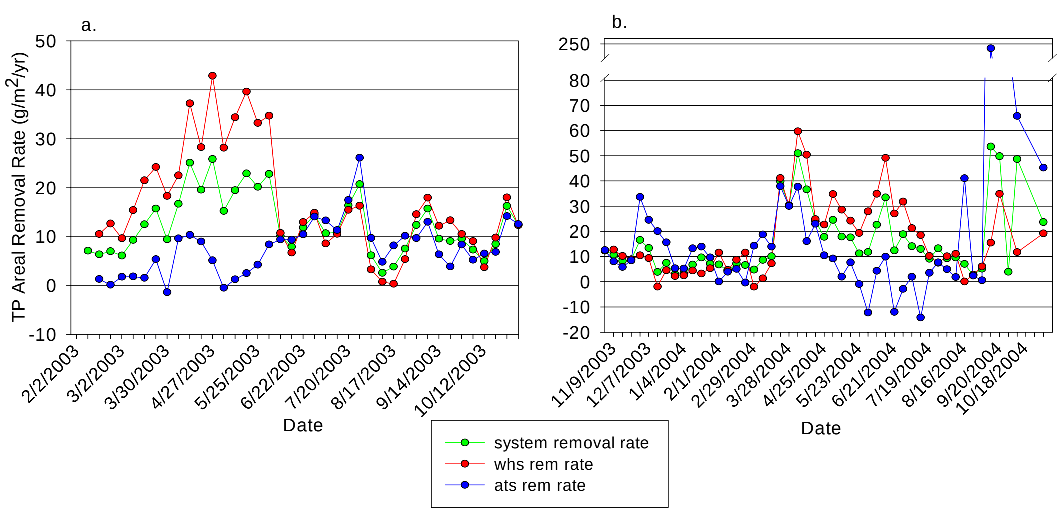


Figure 2-31: Total Phosphorus areal removal rates for the period January 27, 2003 through October 18, 2004. Figure (a.) represents Quarters 1-3, concentration reduction study; Figure (b.) represents Quarters 4-6, load reduction study.

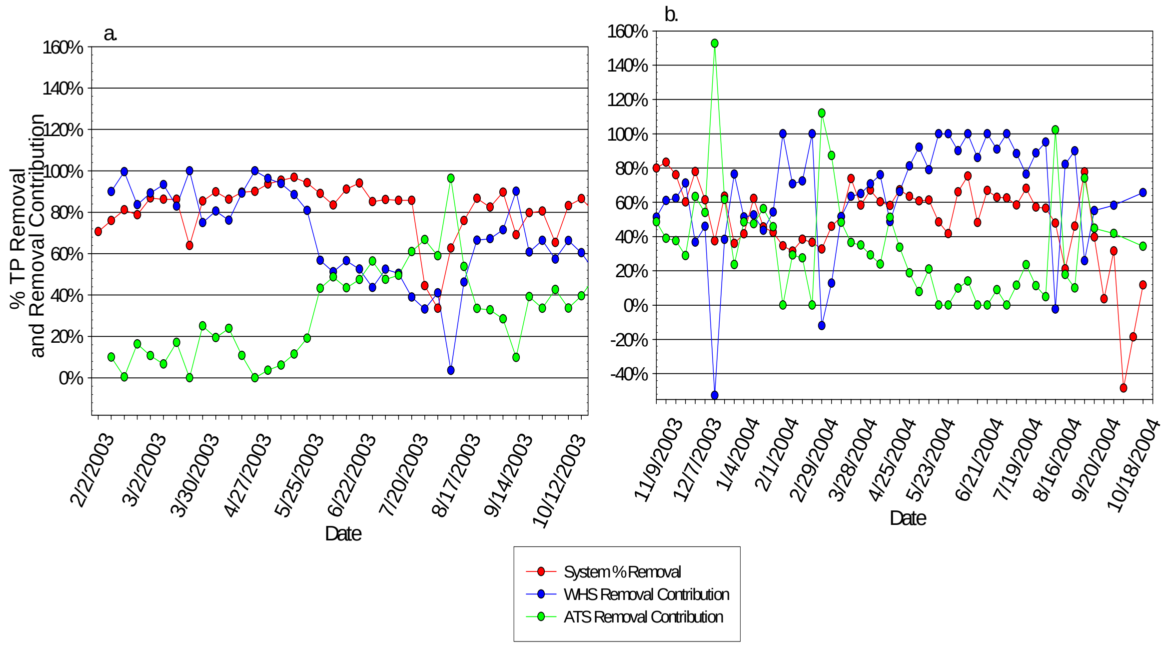


Figure 2-32: Comparative total phosphorus concentrations including WHS™ contribution for the period January 27, 2003 through October 18, 2004. Figure (a.) represents Quarters 1-3, concentration reduction study; figure (b.) represents Quarters 4-6, load reduction study.

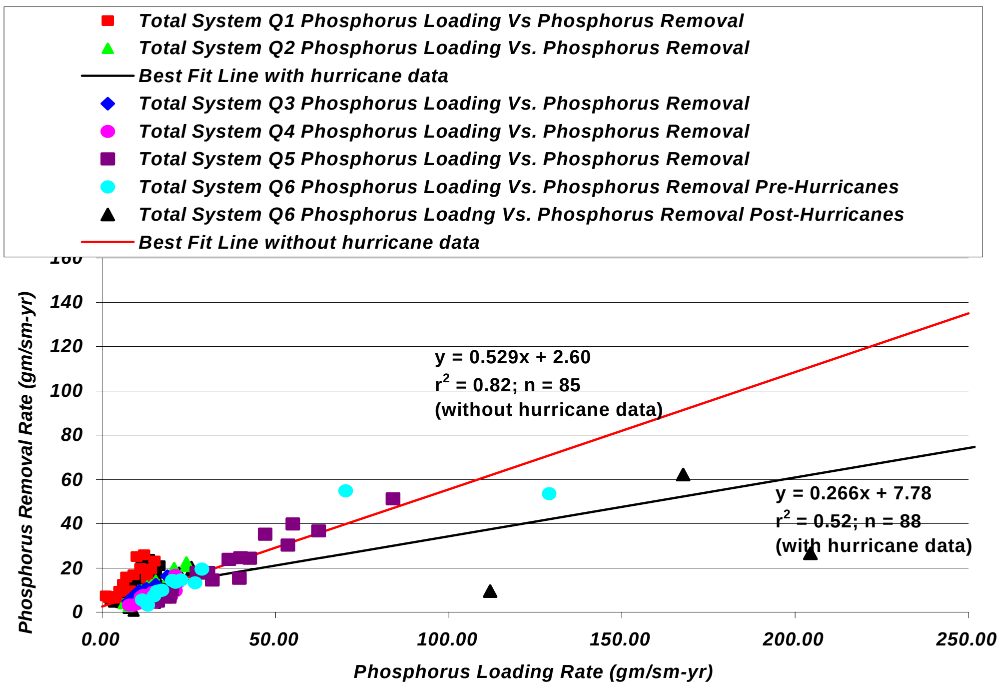


Figure 2-33: Comparative total phosphorus areal loading and areal removal rates

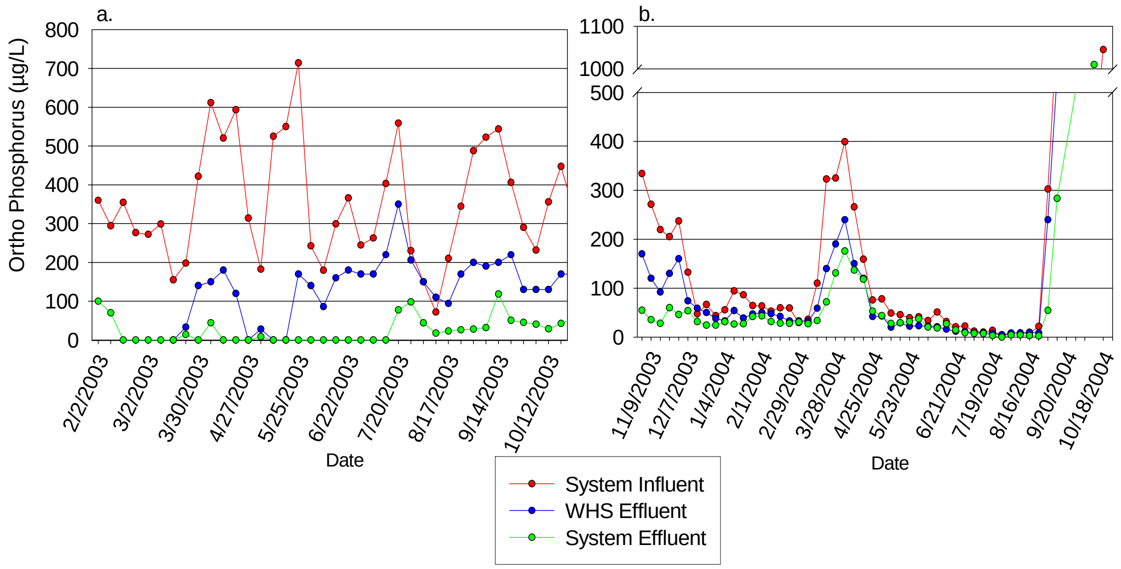


Figure 2-34: Comparative ortho phosphorus concentrations including WHS™ contribution for the period January 27, 2003 through October 18, 2004. Figure (a.) represents Quarters 1-3, concentration reduction; figure (b.) represents Quarters 4-6, load reduction study.

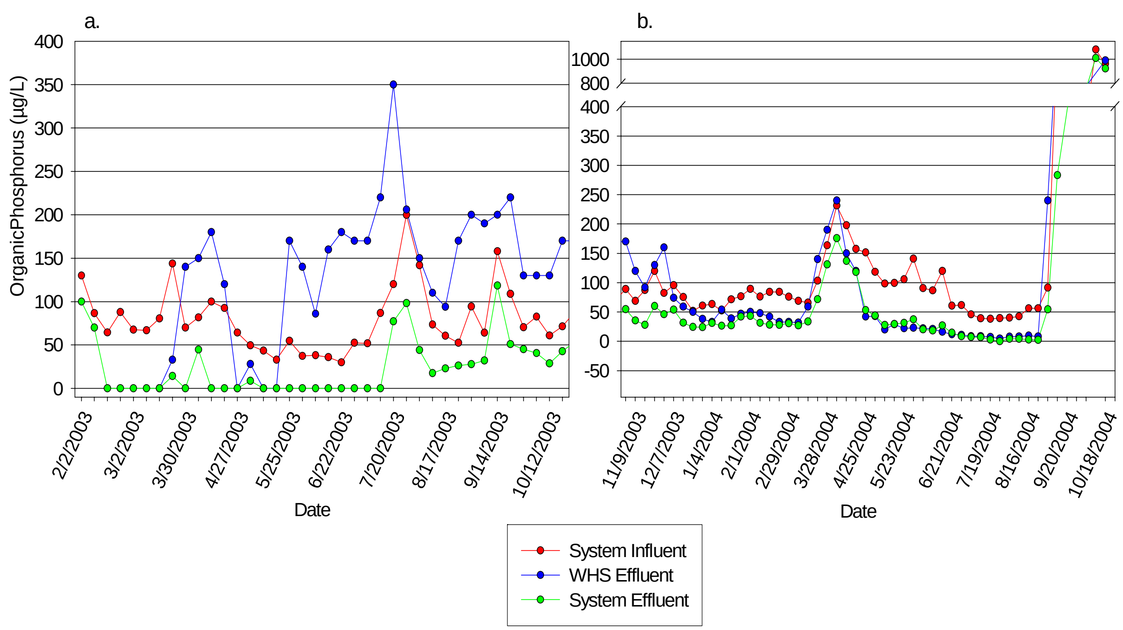


Figure 2-35: Comparative organic phosphorus concentrations including WHS™ contribution for the period January 27, 2003 through October 18, 2004. Figure (a.) represents Quarters 1-3, concentration reduction; figure (b.) represents Quarters 4-6, load reduction study.

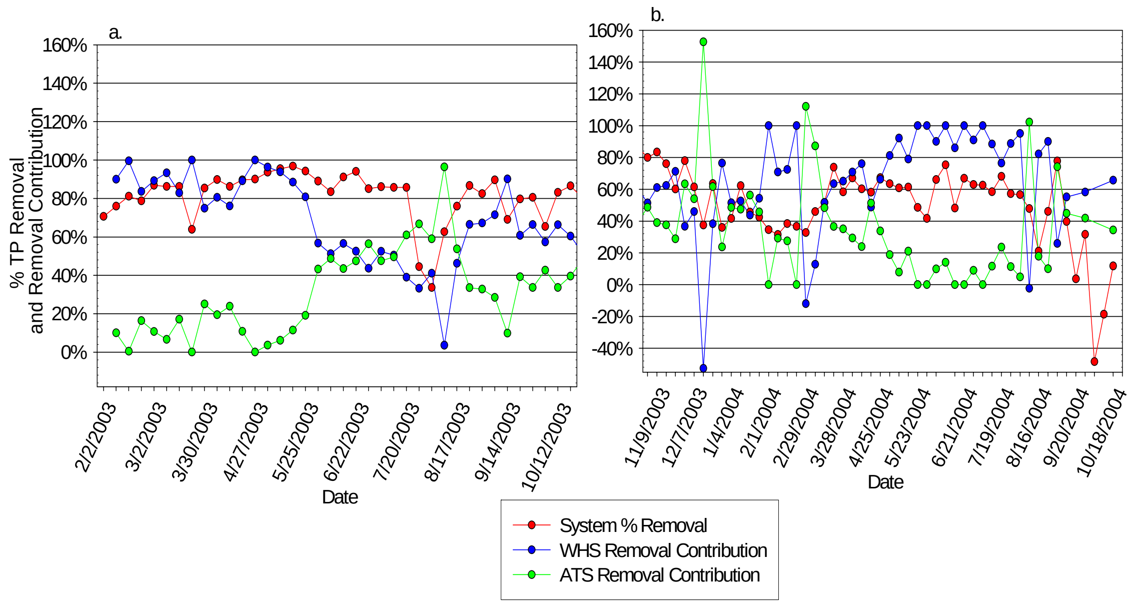


Figure 2-36: Comparative total phosphorus removal contributions for the period January 27, 2003 through October 18, 2004. Figure (a.) represents Quarters 1-3, concentration reduction study; figure (b.) represents Quarters 4-6, load reduction study.

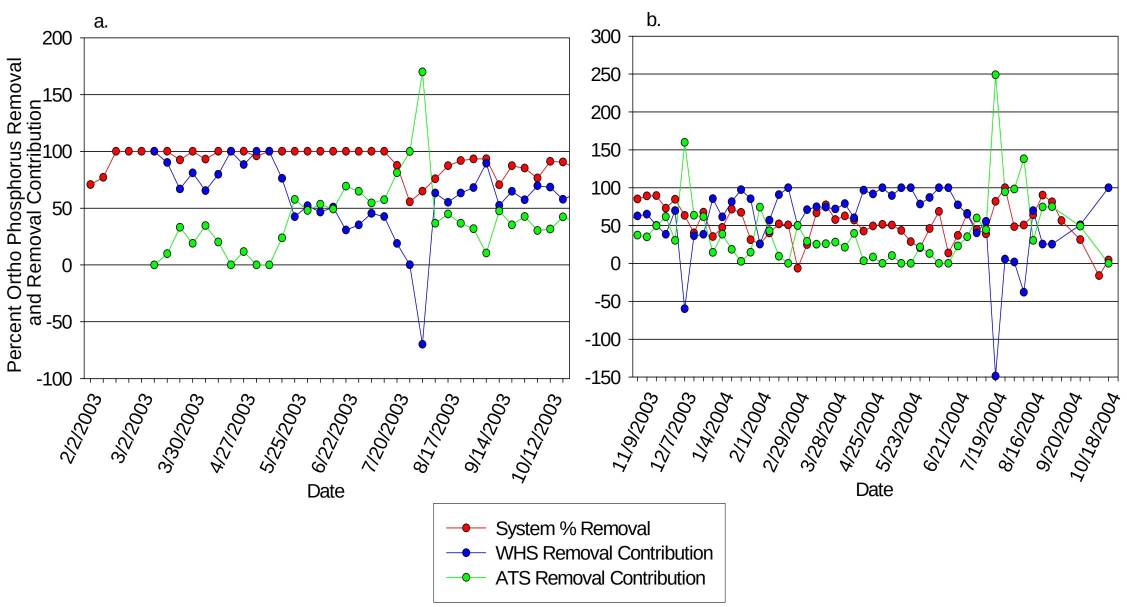


Figure 2-37: Comparative ortho phosphorus removal contributions for the period January 27, 2003 through May 31, 2004. Figure (a.) represents Quarters 1-3, concentration reduction study; figure (b.) represents Quarters 4-6, load reduction study.

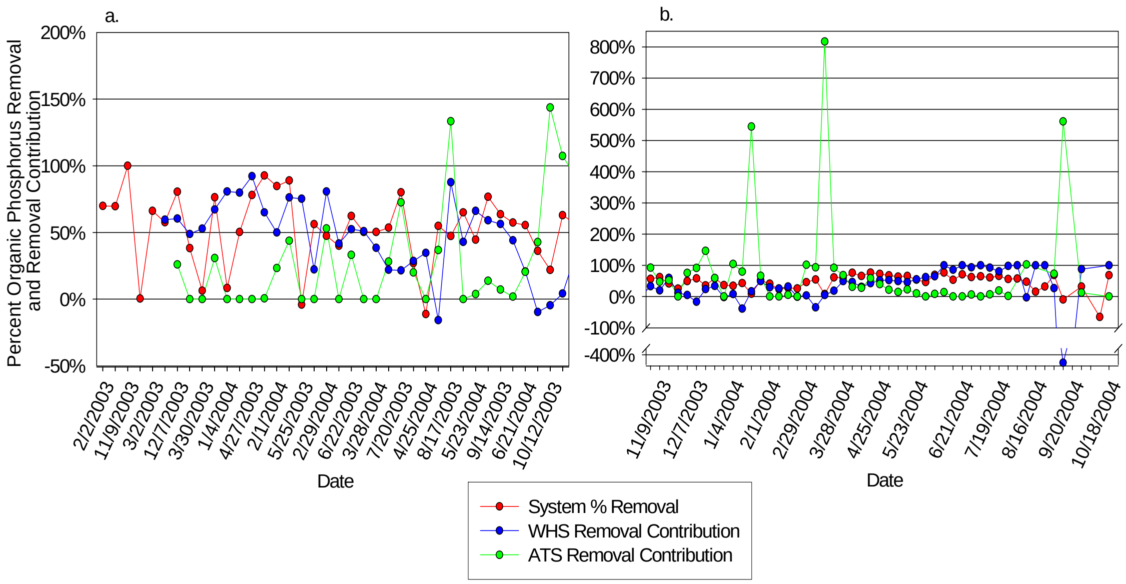


Figure 2-38: Comparative organic phosphorus removal contributions for the period January 27, 2003 through May 31, 2004. Figure (a.) represents Quarters 1-3, concentration reduction study; figure (b.) represents Quarters 4-6, load reduction study.

To gain some insight into the presence of alkaline phosphatase or other enzymatic activity within the system as it relates to organic phosphorus reduction, it is helpful to look at proportional treatment contributions within the WHS™ such as presented within Figures 2-36 through 2-38. While conclusive statements can not be made from comparison of grab data to flow weighted composite data, as represented within these figures, there is some indication that the WHS™ and ATS™ contributed proportionally to the reduction of total, ortho and organic phosphorus. The data set is also shown on a quarterly basis in Table 2-18.

Table 2-18: Quarterly phosphorus removal data for the period December 23, 2002 through November 3, 2003

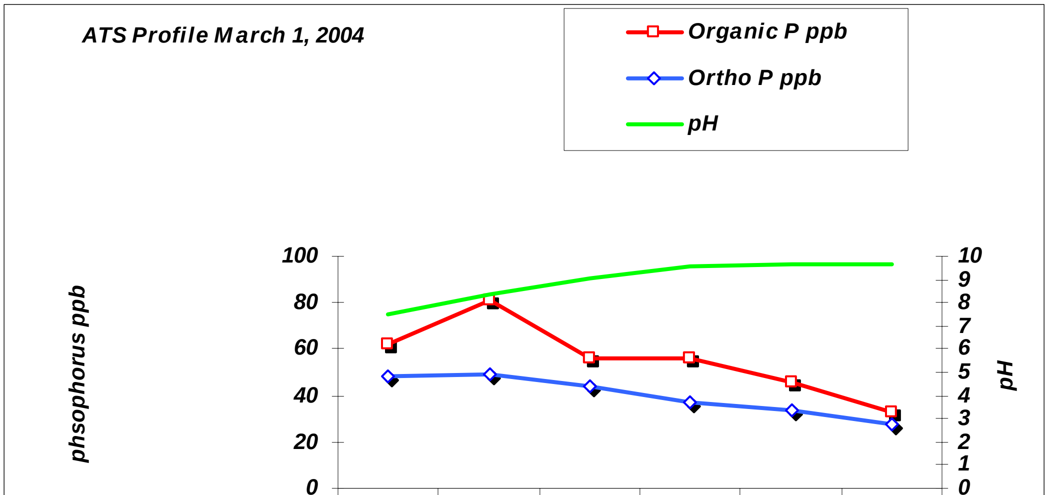
Parameter	Q1		Q2	
	% removed of total load	% contribution of removed load	% removed of total load	% contribution of removed load
System Total P	87.0	100	83.3	100
ATS™ Total P	9.3	10.53	34.7	41.72
WHS™ Total P	77.7	89.47	48.6	58.28
System Ortho P	97.6	100	94.2	100
ATS™ Ortho P	11.8	11.8	42.9	45.6
WHS™ Ortho P	86.8	88.2	51.3	54.4
System Organic P	64.8	100	51.8	100
ATS™ Organic P	4.4	6.6	11.2	21.8
WHS™ Organic P	60.4	93.4	40.6	78.2

Parameter	Q3		Q4	
	% removed of total load	% contribution of removed load	% removed of total load	% contribution of removed load
System Total P	80.7	100	49.5	100
ATS™ Total P	30.5	37.8	26.4	50.1
WHS™ Total P	50.2	62.2	26.5	49.9
System Ortho P	88.0	100	53.9	100
ATS™ Ortho P	34.3	39.2	8.4	13.6
WHS™ Ortho P	53.7	60.8	53.1	86.4
System Organic P	54.2	100	38.9	100
ATS™ Organic P	15.8	29.0	22.7	58.3
WHS™ Organic P	38.4	71.0	16.2	41.7

Parameter	Q5		Q6	
	% removed of total load	% contribution of removed load	% removed of total load	% contribution of removed load
System Total P	55.9	100	39	100
ATS™ Total P	15.7	30.9	318	26.5
WHS™ Total P	40.2	69.1	31	74.5
System Ortho P	46.9	100	50	100
ATS™ Ortho P	8.43	18.7	40	65
WHS™ Ortho P	36.7	81.3	10	35
System Organic P	47	100	43	100
ATS™ Organic P	37.4	79.5	52	52
WHS™ Organic P	9.6	21.5	48	48

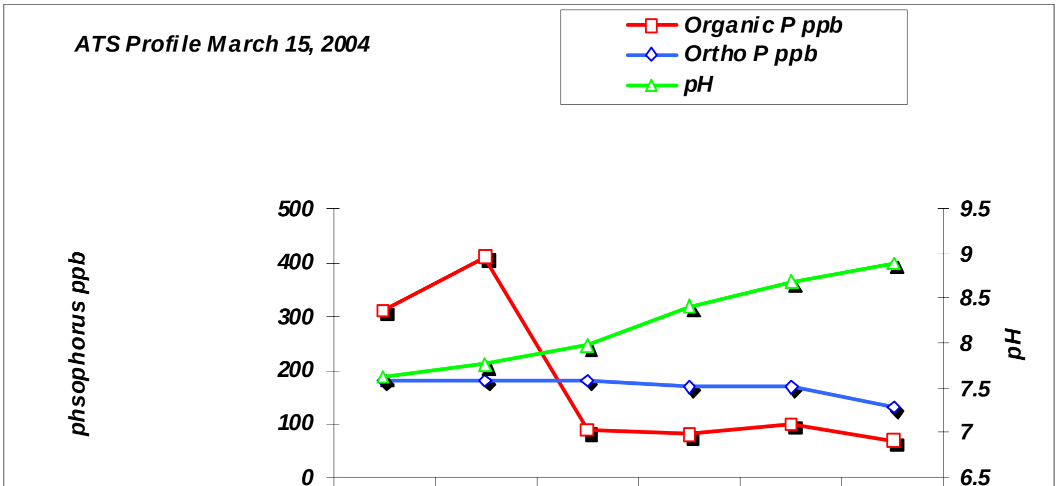
This review provides some indication that enzymatic activity may have been predominantly occurring in the WHS™, as organic phosphorus reduction is noted primarily within the WHS™ during the early quarters.. However, ATS™ involvement is more evident in the second through the sixth quarter. One approach that was contemplated for enhancing organic phosphorus removal would be a second stage WHS™ that receives effluent from the ATS™. Such a system would also serve to reduce effluent pH while modulating temperature within the ATS™ effluent. During the third quarter a bench scale study was conducted to investigate the efficacy of a second stage WHS™. The results provide indication that while such a system is very effective in modulating pH and temperature, its capability to reduce organic phosphorus is comparatively modest.

Additional testing was also completed on the ATS™ unit to help clarify the issue of activity of alkaline phosphatase or PDEase upon the ATS™. For a period of four weeks, grab samples were obtained down the length of the ATS™ floway at set intervals. These samples were analyzed for total, ortho and organic phosphorus. The results are noted in Figures 2-39 through 2-42. It is clear from these findings that hydrolysis of organic phosphorus is occurring, for the removal of organic phosphorus exceeds that of ortho phosphorus. This indicates that ortho phosphorus is being generated through hydrolysis of organic phosphorus at a rate equal to or greater than the uptake rate of ortho phosphorus. This remained consistent through the testing period, even through weekly harvesting—indicating an active production of enzymes within a standing base crop. In addition, because the ATS™ does not support extensive accretion and sediment accrual, the targeted organic phosphorus is that attendant with the water column, rather than stored organic phosphorus within the sediment.



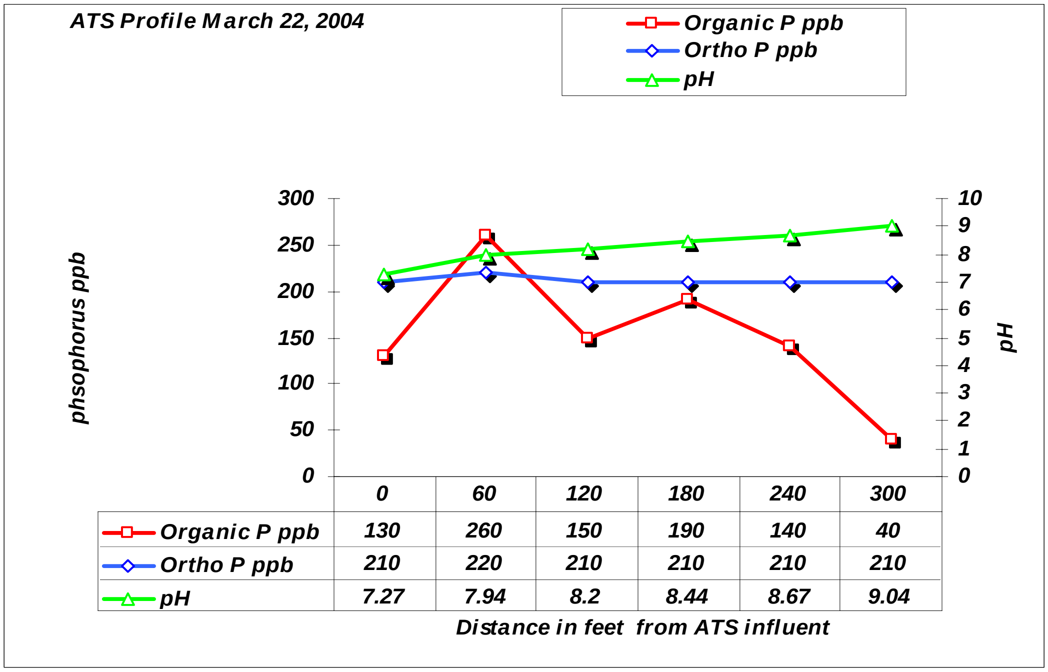
Distance in feet from ATS influent	0	60	120	180	240	300
Organic P ppb	62	81	56	56	46	33
Ortho P ppb	48	49	44	37	34	28
pH	7.49	8.4	9.06	9.6	9.67	9.69

Figure 2-39: ATS™ phosphorus profile March 1, 2004



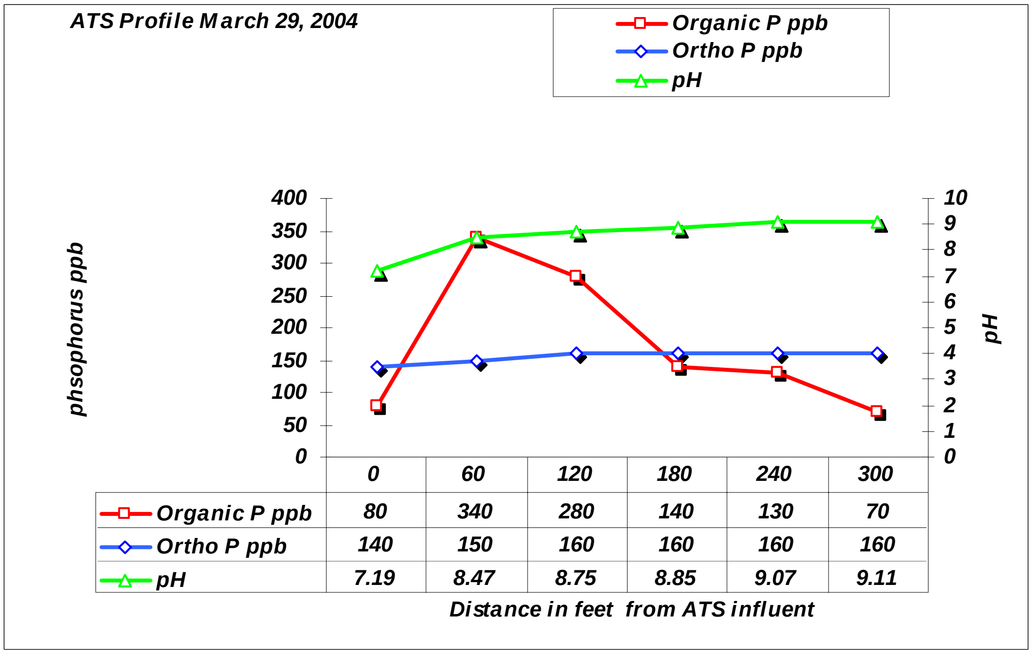
Distance in feet from ATS influent	0	60	120	180	240	300
Organic P ppb	310	410	90	80	100	70
Ortho P ppb	180	180	180	170	170	130
pH	7.63	7.78	7.98	8.42	8.7	8.91

Figure 2-40: ATS™ phosphorus profile March 15, 2004



	0	60	120	180	240	300
Organic P ppb	130	260	150	190	140	40
Ortho P ppb	210	220	210	210	210	210
pH	7.27	7.94	8.2	8.44	8.67	9.04

Figure2-41: ATS™ phosphorus profile March 22, 2004



	0	60	120	180	240	300
Organic P ppb	80	340	280	140	130	70
Ortho P ppb	140	150	160	160	160	160
pH	7.19	8.47	8.75	8.85	9.07	9.11

Figure 2-42: ATS™ phosphorus profile March 22, 2004

NITROGEN REDUCTION

Outflow Concentration Optimization Period

Because of the low N:P ratio within the L-62 water, it was anticipated that nitrogen would need to be supplemented within the system to optimize phosphorus reduction. This was discussed in some detail within the Preliminary Engineering Report. Consequently, a nitrogen supplementation program was implemented upon initiation of WHS™ - ATS™ system operation. The intent was to provide nitrogen such that the N:P ratio was adjusted upward from an existing level of about 4:1 to a level at least comparable to the N:P ratio within the plant tissue - a value of about 8:1 to15:1. Initially nitrogen was added only to the WHS™ via the influent Parshall flume as potassium nitrate (KNO_3 at 13.2 % N). Later it was found beneficial to provide additional nitrogen to the ATS™ to enhance algae production. Urea at 45% N was used as well as potassium nitrate as a nitrogen source later in Q1, although urea was not added to the ATS™ in an effort to reduce the chance of discharge of unionized ammonia in the high pH daytime effluent. During the second quarter some urea was also added through irrigation within the WHS™.

With supplementation of nitrogen it was also necessary to ensure that there was no net discharge of nitrogen, i.e. that effluent loads remained lower than pre-supplemented influent loads. As noted in Figure 2-14 and 2-15, as previously presented, effluent nitrogen loads and concentrations remained lower than influent loads and concentrations throughout Q1, Q2 and Q3. The monthly supplementation quantities are noted in Table 2-19.

During Q1, the system received from a total flow of 41.27 million gallons from the L-62 canal, 749.38 pounds of total nitrogen, with weekly loads ranging from 30.63 to 78.33 pounds. The weekly concentration of influent total nitrogen ranged from 1.11 mg/l to 2.85 mg/l, with a mean of 2.18 mg/l. The total nitrogen discharged with the system effluent was 545.00 pounds, with the weekly load ranging from 19.82 to 76.45 pounds, associated with a total flow 37.70 million gallons. The weekly concentration of effluent total nitrogen ranged from 0.82 to 2.81 mg/l, with a mean of 1.73 mg/l. The percent removal for total nitrogen loads from L-62 averaged 27.3%, ranging from 1.27% to 45.73%. The percent removal for all incoming nitrogen loads, including 498.2 pounds of supplemented nitrogen averaged 56.3%

During Q2, the system received from a total flow of 40.92 million gallons from the L-62 canal 729.45 pounds of total nitrogen, with weekly loads ranging from 34.68 to 70.36 pounds. The weekly concentration of influent total nitrogen ranged from 1.40 mg/l to 2.81 mg/l, with a mean of 2.14 mg/l. The total nitrogen discharged with the system effluent was 528.43 pounds, with the weekly load ranging from 27.92 to 54.79 pounds, associated with a total flow 37.60 million gallons. The weekly concentration of effluent total nitrogen ranged from 1.20 to 1.91 mg/l, with a mean of 1.69 mg/l. The percent removal for total nitrogen loads from L-62 averaged 27.6%, ranging from 0% to 45.83%. The percent removal for all incoming nitrogen loads, including 731.2 pounds of supplemented nitrogen averaged 63.8%

During Q3, the system received from a total flow of 35.28 million gallons from the L-62 canal 830.97 pounds of total nitrogen, with weekly loads ranging from 37.34 to 178.94 pounds. The weekly concentration of influent total nitrogen ranged from 1.89 mg/l to 14.40 mg/l, with a mean of 2.82 mg/l. The total nitrogen discharged with the system effluent was 628.48 pounds, with the weekly load ranging from 34.67 to 67.51 pounds, associated with a total flow 36.31 million gallons. The weekly concentration of effluent total nitrogen ranged from 1.40 to 3.37 mg/l, with a mean of 2.08 mg/l. The percent removal for total nitrogen loads from L-62 averaged 24.4%, ranging from –56.82% to 85.38%. The percent removal for all incoming nitrogen loads, including 835.6 pounds of supplemented nitrogen averaged 62.3%

Of the total nitrogen in the influent and effluent, the majority was in the form of organic nitrogen (TON) as noted previously in Table 2-9. For Q1, of the total 749.38 lbs of influent nitrogen, 0.5% was as nitrate nitrogen, 8.6% was ammonia nitrogen, and the remaining 90.9% was organic nitrogen. For the same period, of the 545.00 lbs of effluent nitrogen, 1.8% was as nitrate nitrogen, 11.3% as ammonia nitrogen, and the remaining 86.9% as organic nitrogen.

For Q2, of the total 729.45 lbs of influent nitrogen, 0.2% was as nitrate nitrogen, 19.2 % as ammonia nitrogen, and the remaining 80.6% as organic nitrogen. For the same period, of the 528.43 lbs of effluent nitrogen, 2.5% was as nitrate nitrogen, 11.0% as ammonia nitrogen, and the remaining 86.5% as organic nitrogen.

For Q3, of the total 830.97 lbs of influent nitrogen, 3.8% was as nitrate nitrogen, 17.6% as ammonia nitrogen, and the remaining 78.6% as organic nitrogen. For the same period, of the 628.48 lbs of effluent nitrogen, 4.5% was as nitrate nitrogen, 3.9% as ammonia nitrogen, and the remaining 91.6% as organic nitrogen.

During Q1, total nitrogen areal removal rates for the entire system, with a process area of 10,120 square meter WHS™ and an active ATS™ area of 8,311 square meters (deducting dry areas within the floways) averaged 64.19 g-N/m^2-year, with a standard deviation of 28.81 g-N/m^2-year. During Q2, total nitrogen areal removal rates for the entire system increased to 92.68 g-N/m^2-year, with a lower standard deviation of 10.86 g-N/m^2-year. During Q3, total nitrogen areal removal rates for the system increased to 108.53 g-N/m^2-year, with a standard deviation of 54.90 g-N/m^2-year. For the combined Q1+Q2+Q3 period, total nitrogen areal removal rates for the entire system, averaged 84.32 g-N/m^2-year, with a standard deviation of 38.93 g-N/m^2-year.

During the week ending 9/1/03 the total nitrogen concentration of the influent was very high (14.40 mg/l), even exceeding recorded historical maximums for S-154. The laboratory retested the sample, and found the results to be similar. It would appear this is an outlier value, and possibly the result of contamination from the urea used in supplementation. However, there is a corresponding rise in effluent total nitrogen the following week, indicating there might well have been a spike in the influent. Herbicide applications were done during the week ending 9/1/03, and this could be partly responsible for this high value. The whole issue of nitrogen contamination has been discussed, and since the end of Q3, measures have been taken to reduce the possibility of contamination of samples with urea. If the 9/1/03 data is considered an outlier, then for Q3, there would still be noted a net removal of nitrogen of about 50 pounds. For purposes of this reporting this outlier is included in the data set.

Estimates were also made for areal removal rates for total nitrogen for the WHS™ and the ATS™ using the grab sample data from the WHS™, and nitrogen supplementation data. These estimates are shown as Figures 2-49 and 2-50. Included in the graph is the data for 3/24/03 and 3/31/03, which may be outliers, with total nitrogen of 4.10 mg/l for the WHS™. During Q1, the WHS™ averaged a nitrogen removal rate of 96.17 g/m^2 –yr, ranging from 21.85 to 141.34 g/m^2 –yr, with a standard deviation of 37.27 g/m^2 –yr. For Q1 the ATS™ averaged a nitrogen removal rate of 20.20 g/m^2 –yr, ranging from –5.16 to 104.12 g/m^2 –yr, with a standard deviation of 30.03 g/m^2 –yr. During Q2 rates were increased and less variable noted, with the WHS™ averaging a nitrogen removal rate of 132.10 g/m^2 –yr, ranging from 99.34 to 158.03 g/m^2 –yr, with a standard deviation of 25.18 g/m^2 –yr. For Q2, the ATS™ averaged a nitrogen removal rate of 38.53 g/m^2 –yr, ranging from 14.69 to 60.54 g/m^2 –yr, with a standard deviation of 15.21 g/m^2 –yr. Unlike phosphorus, nitrogen removal dynamics were not seriously impaired by the disruptive event of July. This may be related to the larger number of removal mechanisms (e.g. denitrification and ammonia volatilization) associated with nitrogen dynamics. During Q3 rates were increased and more variable, with the WHS™ averaging a nitrogen removal rate of 154.17 g/m^2 –yr, ranging from 22.43 to 471.32 g/m^2 –yr, with a standard deviation of 112.75 g/m^2 –yr. For Q3, the ATS™ averaged a nitrogen removal rate of 52.95 g/m^2 –yr, ranging from –75.88 to 129.69 g/m^2 –yr, with a standard deviation of 47.42 g/m^2 –yr. This high degree of variability in both the WHS™ and ATS™ is attributable to the high, possibly outlier, value from 9/1/03.

Load Reduction Optimization Period

During Q4, the system received from a total flow of 69.53 million gallons from the L-62 canal 1,018.4 pounds of total nitrogen, with weekly loads ranging from 10.31 to 291.8 pounds. The weekly concentration of influent total nitrogen ranged from 1.26 mg/l to 5.62 mg/l, with a mean of 2.22 mg/l. The total nitrogen discharged with the system effluent was 1,148.4 pounds, with the weekly load ranging from 74.34 to 120.5 pounds, associated with a total flow 65.61 million gallons. The weekly concentration of effluent total nitrogen ranged from 1.39 to 3.58 mg/l, with a mean of 2.15 mg/l. The percent removal for total nitrogen loads from L-62 averaged –8.22%, ranging from –47.02 to 63.52%. The percent removal for all incoming nitrogen loads, including 1,290 pounds of supplemented nitrogen averaged 45.84%.

During Q5, the system received from a total flow of 108.59 million gallons from the L-62 canal 1,359.6 pounds of total nitrogen, with weekly loads ranging from 36.55 to 130.75 pounds. The weekly concentration of influent total nitrogen ranged from 0.59 mg/l to 2.59 mg/l, with a mean of 1.53 mg/l. The total nitrogen discharged with the system effluent was 1,137.11 pounds, with the weekly load ranging from 26.65 to 130.75 pounds, associated with a total flow 99.62 million gallons. The weekly concentration of effluent total nitrogen ranged from 0.59 to 2.39 mg/l, with a mean of 1.44 mg/l. The percent removal for total nitrogen loads from L-62 averaged16.06%, ranging from –37.63 to 59.74%. The percent removal for all incoming nitrogen loads, including 586.8 pounds of supplemented nitrogen averaged 37.33%.

During Q6, the system received from a total flow of 87.98 million gallons from the L-62 canal 1,354.01 pounds of total nitrogen, with weekly loads ranging from 39.94 to 131.0 pounds. The weekly concentration of influent total nitrogen ranged from 1.14 mg/l to 2.88 mg/l, with a mean of 1.89 mg/l. The total nitrogen discharged with the system effluent was 1,310.0 pounds, with the weekly load ranging from 33.41 to 142.1 pounds, associated with a total flow 86.29 million gallons. The weekly concentration of effluent total nitrogen ranged from 1.10 to 3.30 mg/l, with a mean of 1.86 mg/l. The percent removal for total nitrogen loads from L-62 averaged1.0%, ranging from –27.3 to 64.2%. The percent removal for all incoming nitrogen loads, including 710.32 pounds of supplemented nitrogen averaged 35.6%.

For Q4, of the total 1,018.4 lbs of influent nitrogen, 11.4% was as nitrate nitrogen, 8.4% as ammonia nitrogen, and the remaining 80.2% as organic nitrogen. Of the 1,148.4 lbs of effluent nitrogen, 18.9% was as nitrate nitrogen, 0.94% as ammonia nitrogen, and the remaining 80.2% as organic nitrogen. For Q5, of the total 1,359.6 lbs of influent nitrogen, 2.2% was as nitrate nitrogen, 5.9% as ammonia nitrogen, and the remaining 92.0% as organic nitrogen. During this quarter, of the 1,137.1 lbs of effluent nitrogen, 5.8% was as nitrate nitrogen, 1.6% as ammonia nitrogen, and the remaining 92.6% as organic nitrogen. For Q6, of the total 1,354.1 lbs of influent nitrogen, 0.66% was as nitrate nitrogen, 13.5% as ammonia nitrogen, and the remaining 85.9% as organic nitrogen. For the same period, of the 1,310.0 lbs of effluent nitrogen, 5.14% was as nitrate nitrogen, 5.54% as ammonia nitrogen, and the remaining 89.3% as organic nitrogen. Noted in Table 2-19are the relative loads and concentrations for nitrate, ammonia and organic nitrogen.

During Q4, the process area was reduced to 12,049 m^2 total (8,443m^2 of WHS™, plus 3,616 m^2 of ATS™), with the system averaging total nitrogen areal removal rate of 200.9 g-N/m^2-year, with standard deviation 146.5 g-N/m^2-year. This variability is possibly attributable to the increased hydraulic loading rate. The WHS™ average nitrogen removal rate was 206.09 g/m^2 –yr, ranging from –5.42 to 502.65 g/m^2 –yr, with a standard deviation of 165.7 g/m^2 –yr. The ATS™ averaged a nitrogen removal rate of 156.45g/m^2 –yr, ranging from –533.8 to 743.68 g/m^2 –yr, with a standard deviation of 380.8 g/m^2 –yr.

The process area was further reduced during Q5, resulting in a total process area of 8,676 square meters (5,060 m^2 of WHS™, plus 3,616 m^2 of ATS™). Mean total system TN removal rate was 133.7 g-N/m^2-year with a much higher standard deviation of 377.7 g-N/m^2-year. The WHS™ averaged nitrogen removal rate of 19.14 g-N/m^2-year, ranging from 1.42 to 48.4 g/m^2 –yr. The ATS™ averaged a nitrogen removal rate of –1.11g/m^2 –yr, ranging from –31.37 to 7.51 g/m^2 –yr, with a standard deviation of 9.35 g/m^2 –yr. An overall decrease in influent nutrient concentration is likely responsible for this reduction in performance.

During Q6, mean TN removal rate for the system was 149.02 g-N/m^2-year, with standard deviation 103.2 g-N/m^2-year. The WHS™ averaged nitrogen removal rate of 313.46 g-N/m^2-year , ranging from 139.2 to 595.0 g/m^2 –yr. The ATS™ averaged a nitrogen removal rate of –337.7 g/m^2 –yr, ranging from –1,392.0 to 158.0 g/m^2 –yr, with a standard deviation of 417.5 g/m^2 –yr.

For Q4 through Q6, total nitrogen removal averaged 156.24 g-N/m^2-year and standard deviation 118.4 g-N/m^2-year. Post hurricane areal nitrogen removal decreased to about 71 g-N/m^2-year , and net release of nitrogen was observed the weeks of 8/23/2004 and 9/9/2004, following Hurricanes Charlie and Francis. The WHS™ averaged nitrogen removal rate of 264.03 g-N/m^2-year, ranging from –71.23 to 595.1 g/m^2 –yr. For Q6, the ATS™ averaged a nitrogen removal rate of –118.54 g/m^2 –yr, ranging from –1,391.9 to 590.9 g/m^2 –yr, with a standard deviation of 417.5 g/m^2 –yr.

The system-projected performance as presented within the Preliminary Engineering report was a total nitrogen reduction rate of 93.32 g-N/m^2-year, with the WHS™ providing 130.8 g-N/m^2-year and the ATS™ providing 55.8 g-N/m^2-year.

Table 2-19: Nitrogen supplementation to the WHS™ and ATS™ treatment systems for the period January 27, 2003 through October 18, 2004.

Week Ending (Q1)		Nitrogen added as KNO_3 lbs	Nitrogen added as Urea lbs	Total Nitrogen added lbs
2/3/03	WHS™	10.0	0	10.0
	ATS™	0	0	0
2/10/03	WHS™	15.3	0	15.3
	ATS™	0	0	0
2/17/03	WHS™	16.9	0	16.9
	ATS™	0	0	0
2/24/03	WHS™	23.1	0	23.1
	ATS™	2.6	0	2.6
3/3/03	WHS™	27.1	0	27.1
	ATS™	5.5	1.8	7.3
3/10/03	WHS™	27.1	0	27.1
	ATS™	5.3	2.5	7.8
3/17/03	WHS™	13.9	9.0	22.9
	ATS™	13.9	0	13.9
3/24/03	WHS™	13.9	12.6	26.5
	ATS™	13.9	0	13.9
3/31/03	WHS™	13.9	12.6	26.5
	ATS™	13.9	0	13.9
4/7/03	WHS™	13.9	18.0	31.9
	ATS™	13.9	0	13.9
4/14/03	WHS™	13.9	18.0	31.9
	ATS™	13.9	0	13.9
4/21/03	WHS™	13.9	25.2	39.1
	ATS™	13.9	0	13.9
4/28/03	WHS™	13.9	18	31.9
	ATS™	13.9	0	13.9
5/5/03	WHS™	13.9	25.2	39.1
	ATS™	13.9	0	13.9
TOTALS	WHS™	230.7	138.6	369.3
	ATS™	124.6	4.3	128.9
	TOTAL	355.3	142.9	498.2

Table 2-19: Continued

Week Ending (Q2)		Nitrogen added as KNO_3 lbs	Nitrogen added as Urea lbs	Total Nitrogen added lbs
5/12/03	WHS™	13.9	25.2	39.1
	ATS™	13.9	0	13.9
5/19/03	WHS™	13.9	25.2	39.1
	ATS™	13.9	0	13.9
5/26/03	WHS™	13.9	25.2	39.1
	ATS™	13.9	0	13.9
6/2/03	WHS™	13.9	25.2	39.1
	ATS™	13.9	0	13.9
6/9/03	WHS™	13.9	25.2	39.1
	ATS™	13.9	0	13.9
6/16/03	WHS™	13.9	25.2	44.5
	ATS™	13.9	0	13.9
6/23/03	WHS™	13.9	30.6	44.5
	ATS™	13.9	0	13.9
6/30/03	WHS™	13.9	30.6	43.1
	ATS™	13.9	0	13.9
7/7/03	WHS™	13.9	29.3	41.8
	ATS™	13.9	0	13.9
7/14/03	WHS™	13.9	27.9	41.8
	ATS™	19.4	0	19.4
7/21/03	WHS™	13.9	27.9	41.8
	ATS™	19.4	0	19.4
7/28/03	WHS™	13.9	27.9	41.8
	ATS™	19.4	0	19.4
8/4/03	WHS™	13.9	27.9	41.8
	ATS™	19.4	0	19.4
TOTALS	WHS™	180.7	353.3	534.0
	ATS™	197.2	0	197.2
	TOTAL	377.9	353.3	731.2

Table 2-19: Continued

Week Ending (Q3)		**Nitrogen added as KNO_3 lbs**	**Nitrogen added as Urea lbs**	**Total Nitrogen added lbs**
8 /11/03	WHS™	13.9	32.4	46.3
	ATS™	19.4	0	19.4
8/18/03	WHS™	13.9	32.4	46.3
	ATS™	19.4	0	19.4
8/25/03	WHS™	13.9	36.5	50.4
	ATS™	19.4	0	19.4
9/1/03	WHS™	13.9	31.1	45.0
	ATS™	19.4	0	19.4
9/8/03	WHS™	13.9	31.1	45.0
	ATS™	19.4	0	19.4
9/15/03	WHS™	13.9	32.4	46.3
	ATS™	19.4	0	13.9
9/22/03	WHS™	13.9	32.4	46.3
	ATS™	19.4	0	19.4
9/29/03	WHS™	13.9	32.4	46.3
	ATS™	19.4	0	19.4
10/6/03	WHS™	13.9	28.4	42.3
	ATS™	19.4	0	19.4
10/13/03	WHS™	13.9	28.4	42.3
	ATS™	19.4	0	19.4
10/20/03	WHS™	13.9	28.4	42.3
	ATS™	19.4	0	19.4
10/27/03	WHS™	13.9	28.4	42.3
	ATS™	19.4	0	19.4
11/3/03	WHS™	13.9	28.4	42.3
	ATS™	19.4	0	19.4
TOTALS	WHS™	180.7	402.7	583.4
	ATS™	252.2	0	252.2
	TOTAL	432.9	402.7	835.6

Table 2-19: Continued

Week Ending (Q4)		Nitrogen added as KNO3 (lbs)	Nitrogen added as Urea (lbs)	Total Nitrogen added (lbs)
11/10/03	WHS™	13.86	93.15	107.01
	ATS™	16.632	0	16.632
11/17/03	WHS™	13.86	93.15	107.01
	ATS™	19.404	0	19.404
11/24/03	WHS™	13.86	93.15	107.01
	ATS™	19.404	0	19.404
12/1/03	WHS™	13.86	93.15	107.01
	ATS™	13.86	0	13.86
12/8/03	WHS™	13.86	93.15	107.01
	ATS™	9.24	0	9.24
12/15/03	WHS™	13.86	93.15	107.01
	ATS™	9.24	0	9.24
12/22/03	WHS™	13.86	93.15	107.01
	ATS™	9.24	0	9.24
12/29/03	WHS™	13.86	93.15	107.01
	ATS™	9.24	0	9.24
1/5/04	WHS™	13.86	93.15	107.01
	ATS™	9.24	0	9.24
1/12/04	WHS™	6.9	44.1	51
	ATS™	0	0	0
1/19/04	WHS™	0	44.1	44.1
	ATS™	0	0	0
1/26/04	WHS™	0	44.1	44.1
	ATS™	0	0	0
Total	WHS™	131.64	970.65	1102.29
	ATS™	115.5	0	115.5
	Total	247.14	970.65	1217.79

Table 2-19: Continued

Week Ending (Q5)		Nitrogen added as KNO3 (lbs)	Nitrogen added as Urea (lbs)	Total Nitrogen added (lbs)
2/2/04	WHS™	0	44.1	44.1
	ATS™	0	0	0
2/9/04	WHS™	0	9.9	9.9
	ATS™	0	0	0
2/15/04	WHS™	0	6.3	6.3
	ATS™	0	0	0
2/22/04	WHS™	0	5.4	5.4
	ATS™	0	0	0
3/1/04	WHS™	0	5.4	5.4
	ATS™	0	0	0
3/8/04	WHS™	0	5.4	5.4
	ATS™	0	0	0
3/14/04	WHS™	0	5.4	5.4
	ATS™	0	0	0
3/21/04	WHS™	11.88	21.6	33.48
	ATS™	0	0	0
3/28/04	WHS™	11.88	16.65	28.53
	ATS™	0	0	0
4/4/04	WHS™	11.88	21.6	33.48
	ATS™	0	0	0
4/11/04	WHS™	11.88	21.6	33.48
	ATS™	0	0	0
4/18/04	WHS™	11.88	34.65	46.53
	ATS™	1.32	0	1.32
4/25/2004	WHS™	11.88	34.65	46.53
	ATS™	1.32	0	1.32
5/2/2004	WHS™	11.88	34.65	46.53
	ATS™	1.32	0	1.32
5/9/04	WHS™	11.88	34.65	46.53
	ATS™	1.32	0	1.32
5/16/04	WHS™	11.88	34.65	46.53
	ATS™	1.32	0	1.32
5/23/04	WHS™	11.88	34.65	46.53
	ATS™	1.32	0	1.32
Totals	WHS™	130.68	405.9	536.58
	ATS™	9.24	0	9.24
	Total System	139.92	405.9	545.82

Table 2-19: (continued)

Week Ending (Q6)		Nitrogen added as KNO3 (lbs)	Nitrogen added as Urea (lbs)	Total Nitrogen added (lbs)
6/7/04	WHS	13.86	52.65	66.51
	ATS	7.92	10.80	18.72
6/14/04	WHS	11.88	45.00	56.88
	ATS	6.60	9.00	15.60
6/21/04	WHS	11.88	45.00	56.88
	ATS	6.60	9.00	15.60
6/28/04	WHS	11.88	45.00	56.88
	ATS	6.60	9.00	15.60
7/5/04	WHS	11.88	45.00	56.88
	ATS	6.60	9.00	15.60
7/12/04	WHS	10.89	34.42	45.31
	ATS	5.94	8.10	14.04
7/19/04	WHS	5.94	19.12	25.06
	ATS	3.30	4.50	7.80
7/26/04	WHS	5.94	19.12	25.06
	ATS	3.30	4.50	7.80
8/2/04	WHS	5.94	19.12	25.06
	ATS	3.30	4.50	7.80
8/9/04	WHS	5.94	19.12	25.06
	ATS	3.30	4.50	7.80
8/16/04	WHS	5.94	18.67	24.61
	ATS	3.30	3.60	6.90
8/23/04	WHS	5.94	16.87	22.81
	ATS	3.30	5.40	8.70
8/30/04	WHS	5.94	16.87	22.81
	ATS	3.30	4.50	7.80
9/9/04	WHS	4.95	13.50	18.45
	ATS	2.64	3.60	6.24
9/20/04	WHS	5.28	15.97	21.25
	ATS	0.99	1.35	2.34
9/27/04	WHS	5.28	18.00	23.28
	ATS	1.32	2.25	3.57
10/11/04	WHS	9.24	43.20	52.44
	ATS	3.96	5.40	9.36
10/18/04	WHS	9.24	36.00	45.24
	ATS	3.30	4.50	7.80
Total	WHS	147.84	522.67	670.51
	ATS	74.25	103.50	177.75
	Total	**222.09**	**626.17**	**848.26**

Table 2-20: Forms of nitrogen reported as loads and concentrations for the period January 27, 2003 through November 3, 2003

Week Ending (Q1)		Nitrate Load Lbs	Nitrate Mean Concentration mg/l	Ammonia Load lbs	Ammonia Mean Concentration mg/l	TON Load Lbs	TON Mean Concentration mg/l
2/3/03	Influent	0.37	0.02	1.53	0.08	30.80	1.63
	Effluent	0.00	0.00	0.27	0.02	30.27	1.66
2/10/03	Influent	0.53	0.03	2.05	0.11	31.90	1.68
	Effluent	0.00	0.00	0.00	0.00	33.17	1.69
2/17/03	Influent	0.54	0.03	1.42	0.08	43.67	2.53
	Effluent	0.00	0.00	0.00	0.00	25.17	1.71
2/24/03	Influent	0.00	0.00	1.32	0.07	44.84	2.39
	Effluent	0.00	0.00	0.00	0.00	28.95	1.78
3/3/03	Influent	0.00	0.00	2.44	0.10	46.93	1.83
	Effluent	1.15	0.05	3.95	0.17	32.77	1.41
3/10/03	Influent	0.00	0.00	5.04	0.19	44.92	1.66
	Effluent	1.20	0.05	8.13	0.33	32.12	1.32
3/17/03	Influent	0.35	0.01	4.99	0.18	72.99	1.71
	Effluent	2.65	0.09	6.15	0.21	68.05	1.14
3/24/03	Influent	0.00	0.00	3.27	0.11	31.25	1.02
	Effluent	1.44	0.05	4.77	0.15	23.64	0.74
3/31/03	Influent	0.00	0.00	6.31	0.22	60.49	2.11
	Effluent	0.53	0.02	7.31	0.27	41.88	1.54
4/7/03	Influent	0.57	0.02	4.92	0.17	69.61	2.41
	Effluent	0.00	0.00	8.04	0.33	11.78	0.49
4/14/03	Influent	0.00	0.00	5.33	0.18	67.82	2.26
	Effluent	0.00	0.00	4.39	0.17	52.02	2.07
4/21/03	Influent	1.35	0.06	4.53	0.20	48.22	2.10
	Effluent	0.00	0.00	4.62	0.23	38.25	1.86
4/28/03	Influent	0.00	0.00	9.45	0.39	46.16	1.92
	Effluent	0.62	0.03	4.63	0.22	30.23	1.45
5/5/03	Influent	0.00	0.00	10.47	0.42	41.37	1.65
	Effluent	2.44	0.12	9.28	0.47	24.93	1.27
TOTALS	Influent	3.71	0.01	64.70	0.19	680.97	1.98
	Effluent	10.04	0.03	61.75	0.20	473.21	1.51

Table 2-20: Continued

Week Ending (Q2)		Nitrate Load Lbs	Nitrate Mean Concentration mg/l	Ammonia Load lbs	Ammonia Mean Concentration mg/l	TON Load Lbs	TON Mean Concentration mg/l
5/12/03	Influent	1.35	0.06	13.5	0.64	30.81	1.46
	Effluent	0	0	7.45	0.48	20.48	1.32
5/19/03	Influent	0	0	14.64	0.59	55.72	2.33
	Effluent	0	0	8.44	0.42	29.58	1.49
5/26/03	Influent	0	0	6.63	0.24	48.73	1.78
	Effluent	2.00	0.08	4.53	0.17	32.84	1.25
6/2/03	Influent	0	0	8.88	0.32	53.98	1.92
	Effluent	0	0	7.12	0.22	46.40	1.45
6/9/03	Influent	0	0	16.62	0.58	38.99	1.92
	Effluent	0	0	5.86	0.23	26.19	1.05
6/16/03	Influent	0	0	15.07	0.54	40.30	1.46
	Effluent	2.17	0.09	5.38	0.23	28.76	1.21
6/23/03	Influent	0	0	7.27	0.26	49.98	1.78
	Effluent	1.91	0.07	8.74	0.31	34.54	1.24
6/30/03	Influent	0	0	6.31	0.23	47.90	1.77
	Effluent	2.94	0.11	3.16	0.12	33.97	1.28
7/7/03	Influent	0	0	15.81	0.62	51.24	2.00
	Effluent	2.82	0.07	4.21	0.17	37.45	1.53
7/14/03	Influent	0	0	25.77	1.03	40.50	1.61
	Effluent	1.55	0.07	0.86	0.04	34.48	1.54
7/21/03	Influent	0	0	6.92	0.24	46.70	1.62
	Effluent	0	0	0.39	0.01	54.40	1.81
7/21/03	Influent	0	0	0.17	0.01	51.31	2.17
	Effluent	0	0	1.44	0.05	48.96	1.74
7/28/03	Influent	0	0	2.80	0.11	31.88	1.29
	Effluent	0	0	0.75	0.03	28.57	1.17
8/4/03	Influent	0	0	6.46	0.24	49.88	1.89
	Effluent	2.30	0.07	2.39	0.08	38.25	1.24
TOTALS	Influent	1.35	0.00	140.04	0.41	588.06	1.72
	Effluent	13.40	0.04	58.32	0.19	456.71	1.46

Table 2-20: Continued

Week Ending (Q3		Nitrate Load Lbs	Nitrate Mean Concentration mg/l	Ammonia Load lbs	Ammonia Mean Concentratio n mg/l	TON Load Lbs	TON Mean Concentratio n mg/l
8/11/03	Influent	0	0	6.46	0.24	49.28	1.89
	Effluent	2.30	0.07	2.39	0.08	38.25	1.24
8/18/03	Influent	0	0	7.65	0.29	45.08	1.72
	Effluent	2.44	0.09	5.38	0.19	33.70	1.20
8/25/03	Influent	0	0	4.26	0.18	67.10	2.83
	Effluent	1.67	0.06	0.88	0.03	52.56	1.90
9/1/03	Influent	29.82	2.40	91.96	7.20	57.16	4.60
	Effluent	0.64	0.05	1.28	0.10	24.24	1.82
9/8/03	Influent	0	0	6.68	0.45	28.21	1.90
	Effluent	6.18	0.31	7.25	0.36	54.04	2.70
9/15/03	Influent	0.05	0	8.16	0.48	41.91	2.44
	Effluent	4.85	028	2.89	0.17	39.69	2.29
9/22/03	Influent	0.66	0.03	3.99	0.19	47.06	2.28
	Effluent	0	0	0.47	0.02	44.78	2.28
9/29/03	Influent	0.47	0.03	3.32	0.18	36.06	1.94
	Effluent	0	0	1.35	0.05	39.38	2.00
10/6/03	Influent	0.08	0.01	5.48	0.28	34.69	1.76
	Effluent	1.62	0.07	0.95	0.04	32.10	1.63
10/13/03	Influent	0.66	0.02	2.47	0.09	55.63	1.99
	Effluent	4.04	0.15	0.64	0.02	53.81	2.73
10/20/03	Influent	0.08	0.01	2.34	0.08	59.98	2.01
	Effluent	4.64	0.17	0.71	0.03	60.41	3.07
10/27/03	Influent	0	0	1.09	0.04	61.25	2.14
	Effluent	0	0	0.33	0.01	45.69	2.32
11/3/03	Influent	0	0	1.93	0.07	64.38	2.33
	Effluent	0	0	0	0	62.37	3.17
TOTALS	Influent	31.82	0.11	145.80	0.49	648.66	2.19
	Effluent	28.38	0.09	24,53	0.08	581.03	1.92

Week Ending (Q4)		Nitrate Load Lbs	Nitrate Mean Concentration mg/l	Ammonia Load lbs	Ammonia Mean Concentration mg/l	TON Load Lbs	TON Mean Concentration mg/l
11/10/03	Influent	0.00	0.00	1.93	0.07	64.38	2.33
	Effluent	0.00	0.00	0.00	0.00	62.37	2.70
11/24/03	Influent	33.05	0.58	13.51	0.24	272.99	4.80
	Effluent	23.52	0.46	0.00	0.00	93.05	1.81
12/1/03	Influent	35.93	0.65	9.66	0.18	106.13	1.93
	Effluent	9.65	0.19	0.00	0.00	97.86	1.97
12/8/03	Influent	8.62	0.16	8.89	0.16	81.03	1.48
	Effluent	43.25	0.89	0.00	0.00	71.21	1.47
12/15/03	Influent	7.42	0.15	5.47	0.11	49.38	1.00
	Effluent	5.79	0.10	0.49	0.01	73.00	1.28
12/22/03	Influent	46.52	1.05	8.35	0.19	76.78	1.73
	Effluent	4.08	0.10	2.45	0.06	61.48	1.48
12/29/03	Influent	4.20	0.08	17.13	0.34	56.97	1.14
	Effluent	41.75	0.83	1.77	0.04	63.81	1.27
1/5/04	Influent	2.24	0.04	25.03	0.44	62.21	1.10

Week Ending (Q4)		Nitrate Load Lbs	Nitrate Mean Concentration mg/l	Ammonia Load lbs	Ammonia Mean Concentration mg/l	TON Load Lbs	TON Mean Concentration mg/l
	Effluent	27.16	0.46	2.84	0.05	83.76	1.42
1/12/04	Influent	1.93	0.04	12.90	0.23	64.29	1.30
	Effluent	25.50	0.49	0.98	0.02	66.89	1.28
1/19/04	Influent	2.26	0.05	4.33	0.08	77.62	1.61
	Effluent	19.82	0.37	0.00	0.00	98.56	1.86
1/26/04	Influent	10.92	0.21	8.86	0.16	62.42	1.22
	Effluent	32.29	0.62	3.74	0.06	81.62	1.57
TOTALS	Influent	**153.09**	**0.27**	**116.06**	**0.20**	**974.2**	**1.79**
	Effluent	**232.81**	**0.41**	**12.27**	**0.02**	**853.61**	**1.65**

Week Ending (Q5)		Nitrate Load Lbs	Nitrate Mean Concentration mg/l	Ammonia Load lbs	Ammonia Mean Concentration mg/l	TON Load Lbs	TON Mean Concentration mg/l
2/2/04	Influent	6.66	0.13	13.33	0.24	70.10	1.40
	Effluent	33.01	0.65	1.12	0.02	87.22	1.72
2/9/04	Influent	6.95	0.13	13.91	0.25	75.01	1.41
	Effluent	35.62	0.65	1.19	0.02	94.37	1.71
2/16/04	Influent	0.00	0.00	9.15	0.16	74.16	1.41
	Effluent	0.00	0.00	0.00	0.00	70.26	1.30
2/23/04	Influent	0.00	0.00	3.95	0.07	69.45	1.19
	Effluent	0.00	0.00	11.97	0.20	51.06	0.88
3/1/04	Influent	0.00	0.00	1.90	0.03	84.05	1.65
	Effluent	0.00	0.00	0.00	0.00	78.88	1.42
3/8//04	Influent	0.00	0.00	0.00	0.00	82.87	1.60
	Effluent	0.00	0.00	0.00	0.00	77.44	1.45
3/15/04	Influent	0.00	0.00	3.00	0.05	51.05	1.06
	Effluent	0.00	0.00	0.00	0.00	54.96	1.09
3/22/04	Influent	0.00	0.00	0.00	0.00	74.39	1.43
	Effluent	0.00	0.00	0.93	0.02	52.29	1.18
3/29/04	Influent	0.00	0.00	1.62	0.03	108.62	1.96
	Effluent	0.00	0.00	3.36	0.06	89.30	1.93
4/5/04	Influent	0.00	0.00	0.81	0.01	80.63	1.49
	Effluent	0.00	0.00	1.84	0.03	56.23	1.34
4/12/04	Influent	0.00	0.00	3.66	0.06	46.39	1.50
	Effluent	0.00	0.00	0.30	0.01	34.49	1.54
4/19/04	Influent	0.00	0.00	7.92	0.14	74.72	1.40
	Effluent	0.00	0.03	0.00	0.00	66.89	1.46
4/26/04	Influent	1.34	0.03	7.27	0.13	65.13	1.25
	Effluent	0.88	0.00	0.00	0.00	66.89	1.48
5/3/04	Influent	0.00	0.00	0.66	0.01	61.57	1.29
	Effluent	0.00	0.00	0.00	0.00	66.89	1.58
5/10/04	Influent	0.00	0.00	0.00	0.00	65.79	1.33
	Effluent	0.00	0.00	0.00	0.00	66.89	1.50
5/17/04	Influent	0.00	0.00	6.97	0.12	68.15	1.26
	Effluent	0.98	0.00	1.07	0.02	66.89	1.41
5/24/04	Influent	0.00	0.00	2.32	0.04	85.98	1.60
	Effluent	2.73	0.05	0.16	0.00	66.89	1.39
5/31/04	Influent	0.92	0.00	14.64	0.27	124.07	2.30
	Effluent	9.39	0.00	1.42	0.03	68.29	1.45
TOTALS	Influent	15.87	0.02	91.11	0.09	1362.13	1.47
	Effluent	82.61	0.08	23.36	0.02	1216.13	1.44

Week Ending (Q6)		Nitrate Load Lbs	Nitrate Mean Concentration mg/l	Ammonia Load lbs	Ammonia Mean Concentration mg/l	TON Load Lbs	TON Mean Concentration mg/l
6/7/2004	Influent	2.27	0.04	7.76	0.15	88.72	2.33
	Effluent	7.24	0.14	1.50	0.03	66.05	1.73
6/14/2004	Influent	3.48	0.07	23.26	0.44	101.24	1.75
	Effluent	18.42	0.35	0.28	0.01	58.30	1.11
6/21/2004	Influent	2.08	0.04	17.39	0.33	81.40	1.57
	Effluent	2.31	0.04	4.58	0.10	64.59	1.40
6/28/2004	Influent	0.00	0.00	11.30	0.21	78.72	1.62
	Effluent	0.00	0.00	0.75	0.02	63.65	1.46
7/5/2004	Influent	0.97	0.02	5.40	0.10	72.83	1.51
	Effluent	25.10	0.48	1.63	0.03	65.98	1.55
7/12/2004	Influent	0.00	0.00	3.88	0.07	35.97	1.24
	Effluent	3.07	0.06	1.32	0.03	30.55	1.29
7/19/2004	Influent	0.00	0.00	2.98	0.06	58.72	1.24
	Effluent	2.48	0.05	0.84	0.02	51.91	1.15
7/26/2004	Influent	0.00	0.00	3.16	0.06	51.64	1.06
	Effluent	0.00	0.00	0.00	0.00	54.96	1.17
8/2/2004	Influent	0.00	0.00	5.42	0.10	65.67	1.39
	Effluent	0.92	0.02	0.92	0.02	47.26	1.03
8/9/2004	Influent	0.00	0.00	4.00	0.08	49.92	1.06
	Effluent	0.00	0.00	0.00	0.00	46.54	1.00
8/16/2004	Influent	0.00	0.00	14.05	0.27	39.63	1.25
	Effluent	0.55	0.01	1.31	0.03	33.20	1.21
8/23/2004	Influent	0.00	0.00	13.58	0.26	73.37	1.76
	Effluent	0.00	0.00	5.02	0.11	137.05	3.18
8/30/2004	Influent	0.00	0.00	26.23	0.50	75.36	1.98
	Effluent	0.33	0.01	2.50	0.05	90.36	2.45
9/9/2004	Influent	0.00	0.00	15.49	0.29	21.39	0.88
	Effluent	0.00	0.00	31.63	0.67	31.63	1.23
9/20/2004	Influent	0.00	0.00	9.17	0.17	40.19	2.35
	Effluent	1.00	0.02	2.46	0.05	31.96	1.72
9/27/2004	Influent	0.00	0.00	8.01	0.15	32.05	1.45
	Effluent	0.00	0.00	2.82	0.06	51.79	1.48
10/11/2004	Influent	0.00	0.00	4.78	0.09	78.93	1.70
	Effluent	1.54	0.03	12.25	0.26	101.64	2.24
10/18/2004	Influent	0.00	0.00	3.16	0.06	95.08	2.00
	Effluent	1.80	0.03	0.00	0.00	96.10	2.03
Totals	Influent	11.27	0.01	179.87	0.18	1192.74	1.54
	Effluent	64.75	0.07	69.80	0.08	1123.52	1.58

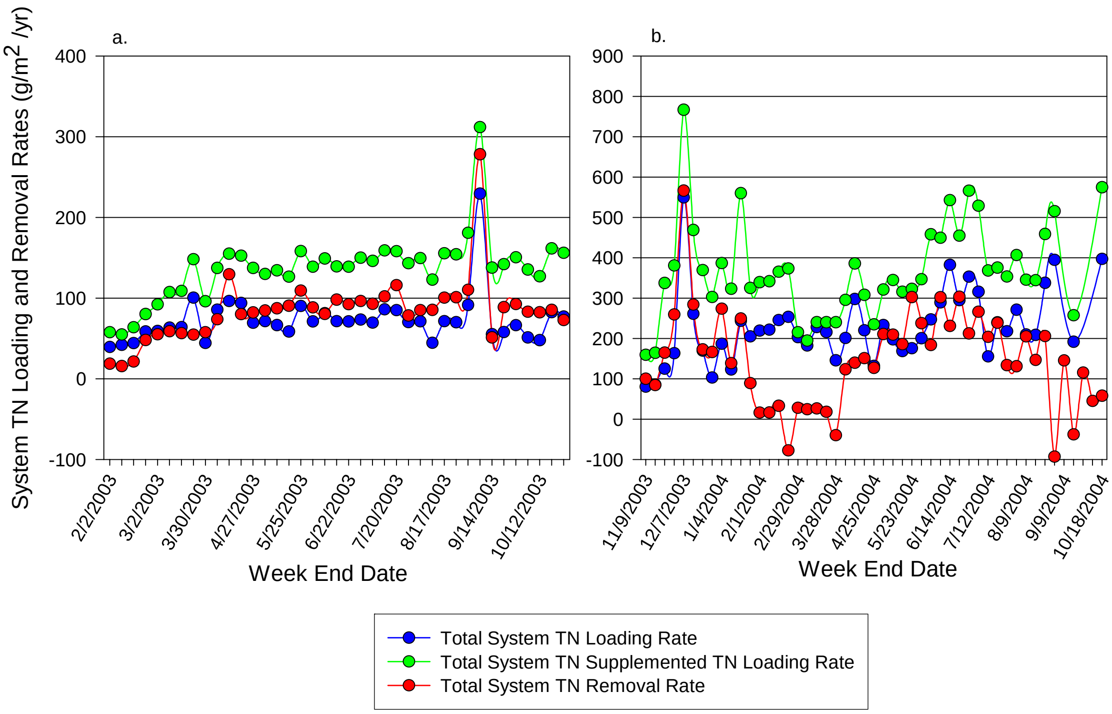


Figure 2-49: Total system total nitrogen areal loading and removal rates for the period January 27, 2003 through October 18, 2004 Figure (a.) represents Quarters 1-3, concentration reduction study; Figure (b.) represents Quarters 4-6, load reduction study.

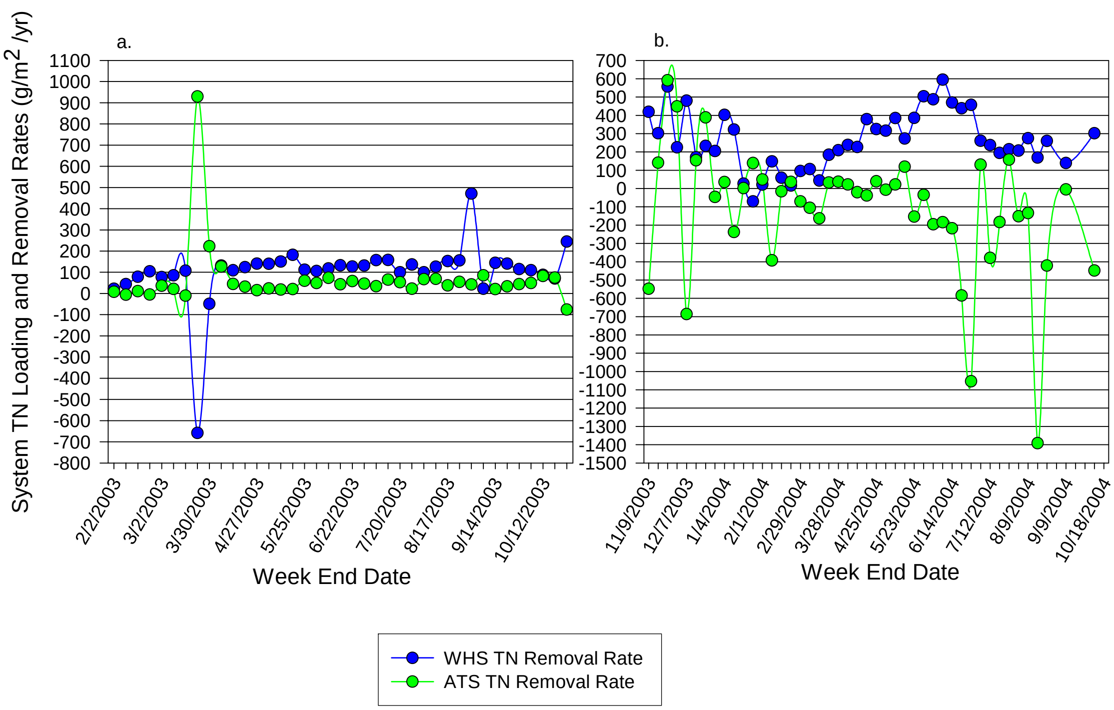


Figure 2-50: Total nitrogen areal removal rates for the WHS™ and ATS™ for the period January 27, 2003 through October 18, 2004. Figure (a.) represents Quarters 1-3, concentration reduction study; 51Figure (b.) represents Quarters 4-6, load reduction study.

IMPACTS UPON DISSOLVED OXYGEN CONCENTRATIONS

The average dissolved oxygen (DO) levels for Q1 were 3.15 mg/l for the influent and 7.78 mg/l for the effluent, representing a gain of 1,208 pounds of oxygen. This resulted in an increase in the average percent saturation from 36% to 88%. The average dissolved oxygen (DO) levels for Q2 were 0.32 mg/l for the influent and 6.51 mg/l for the effluent, representing a gain of 1,932 pounds of oxygen. This resulted in an increase in the average percent saturation from 4% to 84%. The average dissolved oxygen (DO) levels for Q3 were 1.73 mg/l for the influent and 7.19 mg/l for the effluent, representing a gain of 1,665 pounds of oxygen. This resulted in an increase in the average percent saturation from 21% to 90%. The average influent dissolved oxygen for Q4 was 5.01 mg/l and effluent DO was 7.28 mg/l. This represents a gain of 1,057 pounds of oxygen, and an increase in percent saturation from 52% to 72%. For Q5, the mean influent DO was 5.5mg/l with mean effluent DO of 8.81 mg/l, representing a gain of 2,211 pounds of oxygen. This resulted in the average percent saturation increase from 63% to 93%. For Q6, the mean influent DO was 3.2 mg/l with mean effluent DO of 9.1 mg/l, representing a gain of 4,154 pounds of oxygen, and percent saturation was increased from 42% to 111%. These increases brought the water into compliance with the dissolved oxygen standards for recreational surface waters as established by the Florida Department of Environmental Protection (FDEP).

As noted in Table 2-21, and in the previously presented Figures 2-34 and 2-35, the extent of variability and the minimum values indicate a general stabilizing influence of the system upon the DO dynamics within the water source, although there was noted some increase in variability within the effluent DO levels during the summer months of Q2. This stabilization is of critical importance to the maintenance of many aquatic animal resources, including fisheries. As noted, the system relies upon two complimentary factors in the maintenance of stable DO levels—the generation of daytime oxygen through the algal biomass and the reaeration influences at nighttime across the ATS™ floways. This allows attenuation of the typical DO sag phenomenon often characteristic of highly productive systems, such as phytoplankton communities or submerged vascular plant communities. Within the 2-stage WHS™-ATS™ treatment system, the ATS™ serves the function of DO modulation, as levels from the WHS™ are typically below 5.00 mg/l because of the shading and the barrier to reaeration created by the hyacinth biomass.

The DO dynamics within the L-62 canal appeared to be controlled at times by the production of submerged vegetation (hydrilla and coontail) when the surface is not occluded by duckweed. This occurred on a limited number of occasions in April when, on sunny days, the typical DO sag phenomenon was observed. As an example, on April 11, 2003, the DO concentration reached super saturation of 23 mg/l by early afternoon, dropping to 1.37 mg/l by 9:30 in the evening. More typically however, duckweed and water lettuce cover the surface, driving the DO concentration to well below 5.00 mg/l. During Q2, the higher temperatures and heavy duckweed coverage impacted influent DO concentrations, with levels often being at zero. In July, the influent suction line was removed from the bottom of L-62, and floated about four feet below the surface. This resulted in a somewhat higher DO level, although still well below 1 mg/l through August, with some recovery during September and October, although remaining well below saturation. DO levels from the L-62 canal increased during Q4 through Q6, which is likely due to raising the suction line within the water column as well as cooler weather in December through April .

Within the WHS™ there was some modest recovery of DO, largely because of the maintenance of 30-50% open water. The DO was considerably lower in the WHS™ during Q2, because of higher water temperatures, lower influent levels, and possibly because of an increasing benthic oxygen demand. The mean daytime DO for Q1 within the WHS™ was 3.39 mg/l with a maximum of 6.58 mg/l and a minimum of 1.01 and a standard deviation of 1.42 mg/l. The mean daytime DO for Q2 period within the WHS™ fell to 1.50 mg/l with a maximum of 4.43 mg/l and a minimum of 0.27 and a standard deviation of 1.86 mg/l. The mean daytime DO for Q3 period within the WHS™ remained low at 1.34 mg/l with a maximum of 3.79 mg/l and a minimum of 0.78 and a standard deviation of 0.78 mg/l.

The mean daytime DO for Q4 within the WHS™ was higher at 4.02 mg/l with a maximum of 6.05 mg/l and a minimum of 1.57 and a standard deviation of 1.37 mg/l. Q5 mean daytime DO for the WHS™ was 5.25 mg/l, with minimum DO at 2.93 mg/l and maximum at 7.77 mg/l. The standard deviation for Q5 was 1.18mg/l. During Q6, WHS™ DO values were significantly lower, even with respect to influent water DO for this same time period. Average daytime WHS™ DO was 2.3 mg/l (minimum 0.4 mg/l and maximum 6.4 mg/l) with standard deviation 1.45 mg/l. Reasons for this decrease in measured DO are variability in the Hydrolab readings, and more likely, increased biological oxygen demand as evidenced by the high sediment accretion rate for this quarter.

During Q1, the DO levels in the WHS™, proved sufficient to support an active mosquito fish (*Gambusia affinis*) population as well as tadpoles and various insect larvae, but they did not satisfy the previously referenced FDEP standards. The mosquito fish population was sustained throughout Q2 Q3, Q4, Q5 and Q6, but the density and diversity of aquatic invertebrates appeared diminished, as did the tadpole population.

For Q1, the combined ATS™ system (North and South floways), daytime (AM + PM field values) DO concentration prior to the microscreen was typically near or above saturation, with the mean at 9.11 mg/l, the maximum daily average being 11.07 mg/l, the minimum daily average being 7.24 mg/l with a standard deviation of 0.83 mg/l. For Q2, the combined ATS™ daytime (AM + PM) DO concentration prior to the microscreen was also well above saturation, with the mean at 8.84 mg/l, the maximum daily average being 11.65 mg/l, the minimum daily average being 6.37 mg/l with a standard deviation of 1.27mg/l. For Q3, the combined ATS™ daytime (AM + PM) DO concentration prior to the microscreen was also well above saturation, with the mean at 9.28 mg/l, the maximum daily average being 17.02 mg/l, the minimum daily average being 6.62 mg/l with a standard deviation of 1.62 mg/l.

During Q4, the ATS™ daytime (AM + PM) DO concentration prior to the microscreen was greater still, with the mean at 10.72 mg/l, the maximum daily average being 14.91 mg/l, the minimum daily average being 8.18 mg/l with a standard deviation of 1.57 mg/l. During Q5, the ATS™ daytime DO concentration prior to the microscreen showed a mean at 11.15 mg/l, the maximum daily average being 21.8 mg/l, the minimum daily average being 6.02 mg/l with a standard deviation of 1.57 mg/l. During Q6, the ATS™ daytime DO concentration prior to the microscreen showed a mean at 6.41 mg/l, the maximum daily average being 8.37 mg/l, the minimum daily average being 3.09 mg/l with a standard deviation of 0.97 mg/l. The influence of the ATS™ can be better understood when reviewed in parallel with temperature and saturation concentrations, as shown in Figures 2-51 through 2-55. This analysis was not conducted during Q6; a majority of the hourly DO data was lost during the three power outages.

Table 2-21: Summary of dissolved oxygen dynamics for the period January 27, 2003 through May 31, 2004.

Month	Year	January		February		March		April	
		Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
Mean DO (mg/l)	2003			4.85	8.50	2.62	7.66	2.19	7.19
	2004	5.46	8.49	5.43	9.24	5.42	8.60	5.55	8.97
Mean % saturation	2003			52%	95%	31%	87%	26%	84%
	2004	54%	81%	60%	92%	60%	89%	68%	98%
Maximum DO (mg/l)	2003		11.4	9.45	11.08	12.64	9.99	23.00	9.57
	2004	10.79		19.1	12.46	9.65	12.4	8.67	12.02
Minimum DO (mg/l)	2003			0.60	6.59	0.00	6.18	0.00	4.78
	2004	0.00	6.24	1.30	7.17	1.94	5.31	0.00	4.95
Standard Deviation (mg/l)	2003			1.85	0.91	1.88	0.64	2.50	0.73
	2004	2.37	1.28	1.88	1.29	1.68	1.61	1.15	1.4

Month	year	May		June		July	
		Influent	Effluent	Influent	Effluent	Influent	Effluent
Mean DO (mg/l)	2003	0.22	7.28	0.11	6.99	0.54	5.72
	2004	5.43	8.51	4.71	7.19	4.06	6.20
Mean % saturation	2003	3%	93%	1%	89%	7%	75%
	2004	68%	98%	61%	87%	53%	77%
Maximum DO (mg/l)	2003	6.48	9.31	7.14	8.93	6.61	8.96
	2004	8.24	10.1	6.8	8.38	7.76	7.07
Minimum DO (mg/l)	2003	0.00	2.74	0.00	2.60	0.00	3.49
	2004	1.38	7.03	1.71	3.09	0.98	3.43
Standard Deviation (mg/l)	2003	0.67	0.76	0.47	0.69	0.89	1.03
	2004	1.33	0.60	1.19	1.12	1.97	0.91

Month	year	August		September		October	
		Influent	Effluent	Influent	Effluent	Influent	Effluent
Mean DO (mg/l)	2003	0.53	6.66	1.79	7.89	2.88	7.04
	2004	2.49	6.21	0.83	5.73	2.29	6.5
Mean % saturation	2003	7%	87%	23%	99%	34%	85%
	2004	32%	77%	11%	67%	29%	76%
Maximum DO (mg/l)	2003	6.46	16.27	5.99	18.34	6.05	9.43
	2004	5.79	7.07	2.32	6.76	5.09	6.96
Minimum DO (mg/l)	2003	0.00	3.55	0.00	3.65	1.09	2.45
	2004	0.10	3.43	0.08	3.56	0.56	4.48
Standard Deviation (mg/l)	2003	1.25	2.42	1.21	3.42	1.01	0.61
	2004	2.17	0.91	0.77	1.04	1.25	0.61

Table 2-21: Continued

Month	year	November		December	
		Influent	**Effluent**	**Influent**	**Effluent**
Mean DO (mg/l)	2003	4.68	6.53	5.25	7.08
Mean % saturation	2003	52%	66%	52%	69%
Maximum DO (mg/l)	2003	9.43	12.1	10.96	15.5
Minimum DO (mg/l)	2003	1.84	0.0	0.00	0.0
Standard Deviation (mg/l)	2003	0.99	3.18	2.95	2.54

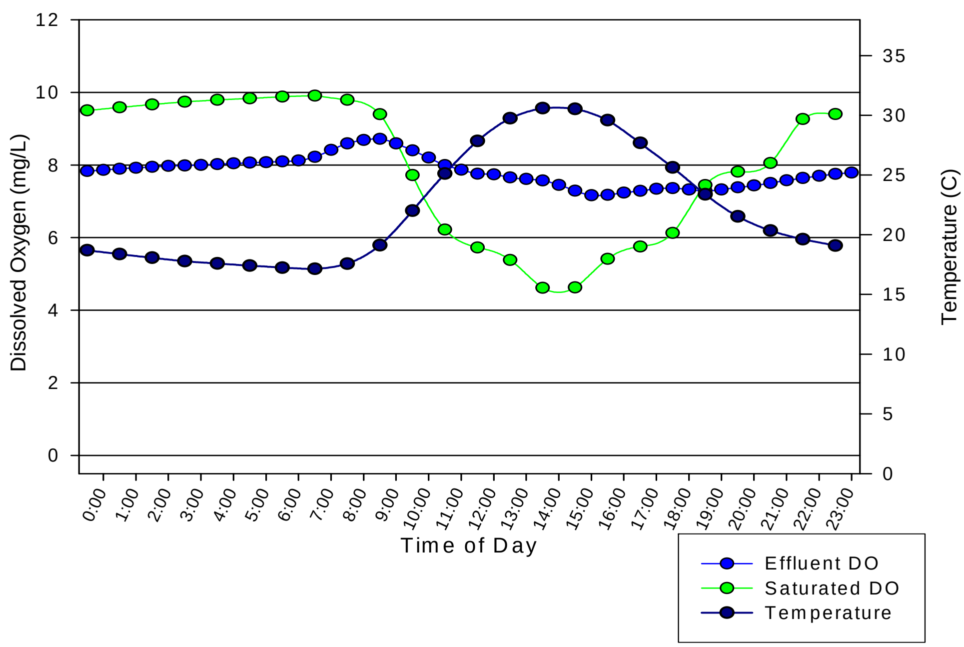


Figure 2-51: Diurnal effluent dissolved oxygen dynamics for Quarter 1, representing the period January 27, 2003 through May 5, 2003

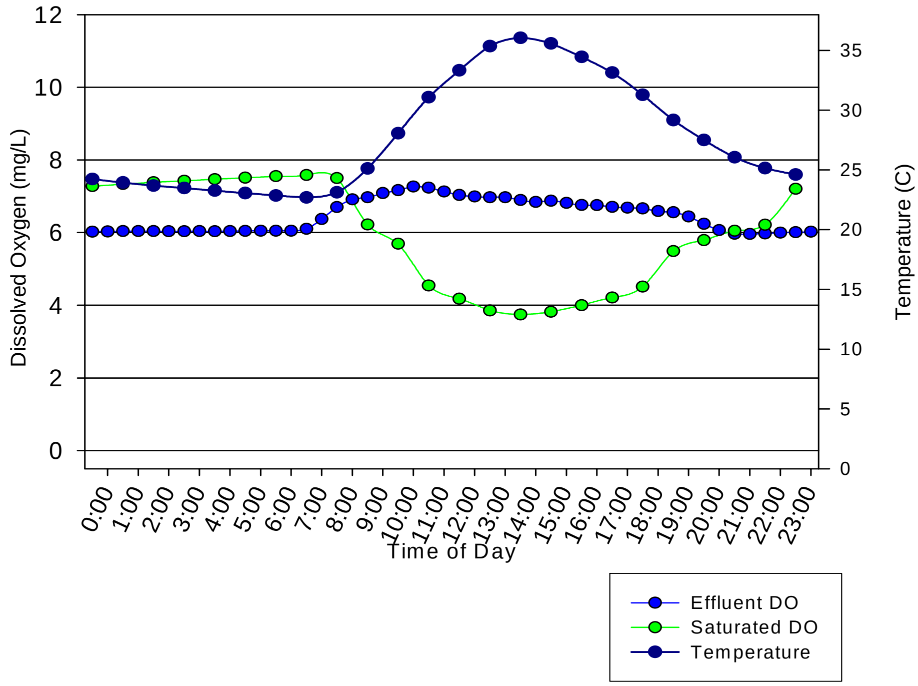


Figure 2-52: Diurnal effluent dissolved oxygen dynamics for Quarter 2, representing the period May 5, 2003 through August 4, 2003

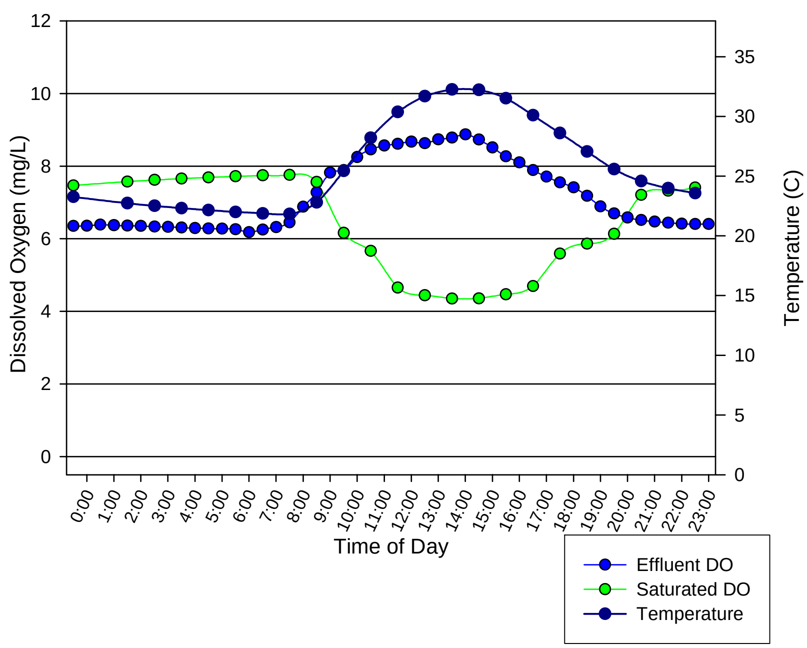


Figure 2-53: Diurnal effluent dissolved oxygen dynamics for Quarter 3, representing the period August 4, 2003 through November 3, 2003

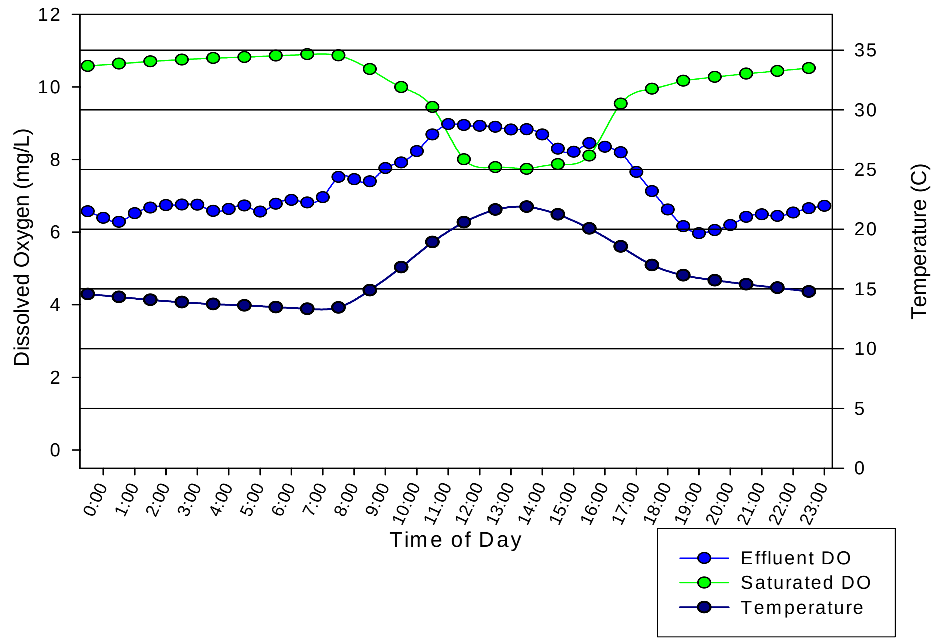


Figure 2-54: Diurnal effluent dissolved oxygen dynamics for Quarter 4, representing the period November 3, 2003 through January 26, 2004.

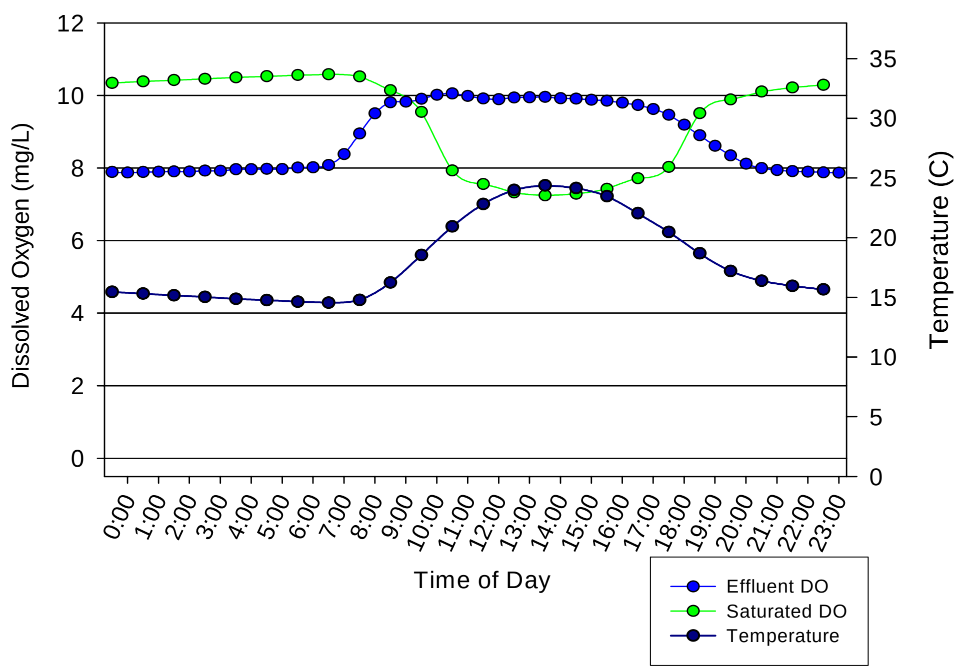


Figure 2-55: Diurnal effluent dissolved oxygen dynamics for Quarter 5, representing the period January 25 through May 31, 2004.

For the period of record, several trends are noted:

- The percent of saturation, represented by the space between the light blue and green lines, increases considerably as the temperature increases. This is likely due to a combination of higher temperatures and increased production and respiration.
- The change in slope for the oxygen level (light blue line) in the early morning is more accentuated and occurs somewhat earlier during the warmer months, likely due to increased photoperiod and more active photosynthesis
- During the daytime the dominance of production is noted by the sustenance of supersaturated or near saturated conditions during the late morning and early afternoon period when water temperature is the highest.
- The point of >100% saturation occurs earlier in the day in the warmer months, indicating active photosynthesis.
- The rate of drop in DO levels in late afternoon increases during the warmer months, particularly noticeable in June through September.
- Super saturation is most consistently sustained in August and September, indicating high levels of productivity.

It is likely that the disruptive event had some influence on DO dynamics within the ATS™, and lower levels and a deeper sag is noted for July, 2003 when compared to the previous months. The overall assessment of this event was presented earlier within this section.

Additional clarification of DO dynamics within the ATS™ is provided through a review of the daytime field sampling for both the north and south treatment units, as noted in Table 2-22 and Figures 2-56 and 2-57 for Q1 through Q3. This analysis was not carried through for the loading rate study, as the north ATS™ unit was taken off-line during that time. The north unit is set at a slope of 2%, while the south unit is set at a slope of 1.5%. As expected, the northern ATS™ treatment unit shows slightly higher DO levels, as noted also in Table 2-22, although the differences are considered minor. This differential is not seen during Q3, suggestive that this degree of difference in floway slope makes little difference, at least when applied to the S-154 conditions of low alkalinity and hardness. Any advantage associated with the higher slope would relate to both the increased velocity, hence an increased reaeration coefficient, and probably to an increased algae production as a result of higher velocities within the northern unit. The role of velocity and boundary layer disruption around the algal cell is discussed in detail within the independent single-stage ATS™ floway report.

As would be expected, AM DO values are higher than PM DO values, because of the lower water temperatures. The AM DO values for Q2 and Q3 are somewhat higher than for Q1, even though Q2 and Q3 temperatures are higher; suggesting Q2 and Q3 experienced higher rates of photosynthesis on the units. The PM DO values for Q2 and to a lesser extent for Q3 however are lower than for Q1, indicating reaeration and temperature influences are more dominant, and productivity less of a factor in the PM. A more detailed discussion of production differences between these two units is presented within Section 4.

Table 2-22: Summary of field AM and PM dissolved oxygen concentrations within the ATS™ effluent for the period January 27, 2003 through November 3, 2003

Quarter 1	North (2% slope)		South (1.5% slope)		Differential % North vs. South	
	AM	PM	AM	PM	AM	PM
Mean DO (mg/l)	9.66	8.88	9.28	8.56	10.8%	3.6%
Maximum DO (mg/l)	11.51	10.78	10.63	10.24	7.6%	5.0%
Minimum DO (mg/l)	7.39	7.18	7.97	6.96	-7.8%	3.1%
Standard Deviation (mg/l)	0.92	0.76	0.66	0.73	28.3%	3.9%

Quarter 2	North (2% slope)		South (1.5% slope)		Differential % North vs. South	
	AM	PM	AM	PM	AM	PM
Mean DO (mg/l)	9.99	8.33	9.78	8.10	2.1%	2.8%
Maximum DO (mg/l)	11.77	9.93	12.20	10.34	-3.7%	-4.1%
Minimum DO (mg/l)	7.51	6.41	7.55	6.58	0.5%	-2.7%
Standard Deviation (mg/l)	1.17	0.85	1.20	0.80	-2.6%	5.8%

Quarter 3	North (2% slope)		South (1.5% slope)		Differential % North vs. South	
	AM	PM	AM	PM	AM	PM
Mean DO (mg/l)	9.99	8.66	9.96	8.72	0.3%	-0.7%
Maximum DO (mg/l)	12.54	16.38	12.56	17.02	-0.2%	-4.0%
Minimum DO (mg/l)	8.13	6.43	8.40	6.12	-3.3%	4.8%
Standard Deviation (mg/l)	1.16	1.70	1.10	1.84	5.1%	-8.2%

Note: This analysis was not continued through Quarters 4 and 5, as the North ATS™ flow way was not in line with the main system.

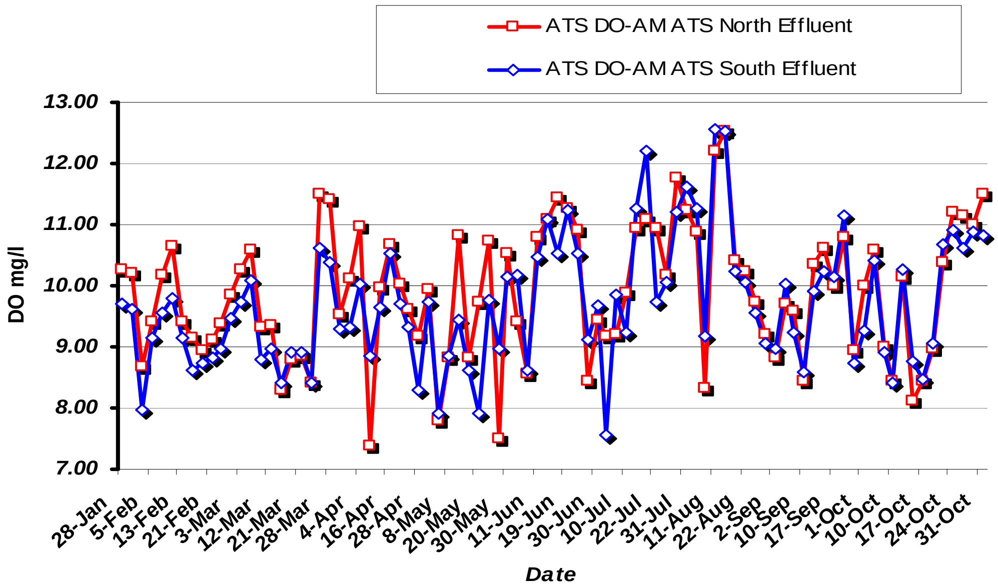


Figure 2-56: Morning (AM) dissolved oxygen (DO) comparative patterns between north and south ATS[TM] treatment for the period January 27, 2003 through November 3, 2003

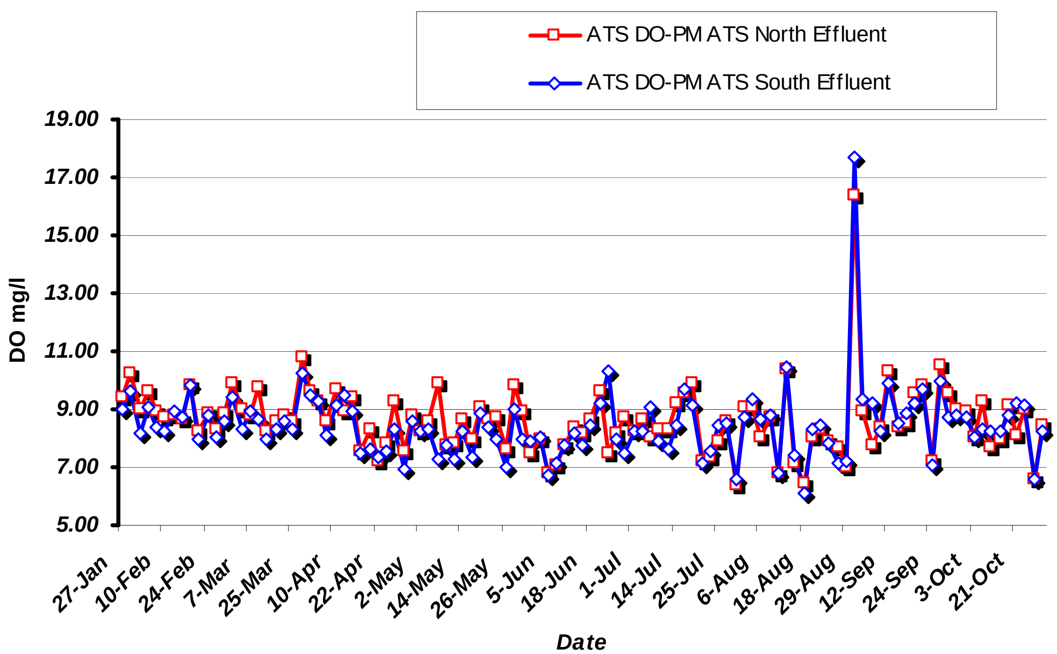


Figure 2-57: Afternoon (PM) dissolved oxygen (DO) comparative patterns between ATS™ North and ATS™ - South treatment units for the period January 27, 2003 through November 3, 2003

REVIEW OF PH FLUCTUATIONS, ALKALINITY AND CARBON AVAILABILITY

During Q1 the mean influent pH was 6.83, while the mean effluent pH was 8.54. During Q2 the mean influent pH was 6.96, while the mean effluent pH was 8.92. During Q3 the mean influent pH was 6.65, while the mean effluent pH was 8.29. During Q4, the mean influent pH was 7.75, while the mean effluent pH was 7.76. For Q5, the mean influent pH was 7.07, while effluent pH was 8.27. Based on Hydrolab pH measurements for Q6, mean influent pH was 6.50 and mean effluent pH was 8.48. The general pH trends were presented previously in Figures 2-26 through 2-32, and are summarized within Table 2- 23.

Table 2-23: Summary of pH trends for the period January 27, 2003 through May 31, 2004.

Month	Year	January		February		March	
		Influent	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
Mean pH	2003	6.79	8.21	6.73	8.43	6.86	8.59
	2004	7.97	7.82	7.62	8.17	6.68	8.04
Maximum pH	2003	7.52	10.32	7.54	10.33	7.52	10.35
	2004	9.91	9.90	8.79	10.35	8.18	9.56
Minimum pH	2003	6.49	7.28	5.64	7.50	6.49	7.48
	2004	3.93	6.62	5.64	6.90	3.73	7.07
Standard Deviation	2003	0.12	0.94	0.15	0.79	0.12	0.96
	2004	0.49	1.14	1.13	1.06	0.50	3.95

Month	Year	April		May		June	
		Influent	**Effluent**	**Influent**	**Effluent**	**Influent**	**Effluent**
Mean pH	2003	6.90	8.60	6.98	8.79	6.95	9.00
	2004	6.79	8.31	6.53	8.52	6.42	8.81
Maximum pH	2003	7.52	10.32	7.98	10.45	8.13	10.58
	2004	7.55	10.0	6.86	9.84	6.95	9.72
Minimum pH	2003	6.49	7.28	6.48	7.20	6.77	7.77
	2004	5.76	6.93	6.13	7.57	6.22	6.84
Standard Deviation	2003	0.12	0.94	0.14	0.91	0.08	0.93
	2004	0.33	0.89	0.17	0.84	.018	0.84

Month	Year	July		August		September	
		Influent	Effluent	Influent	Effluent	Influent	Effluent
Mean pH	2003	6.96	8.98	6.61	8.42	6.64	8.32
	2004	6.49	8.46	6.50	8.35	6.66	8.30
Maximum pH	2003	8.67	10.59	7.69	10.23	7.95	10.07
	2004	8.45	9.15	6.75	9.38	6.95	8.95
Minimum pH	2003	6.36	7.28	4.66	6.65	6.27	6.80
	2004	6.05	7.21	6.26	7.61	6.51	7.53
Standard Deviation	2003	0.03	0.88	0.40	0.93	0.12	0.90
	2004	0.55	0.50	0.14	0.42	0.21	0.36

Month	Year	October		November		December	
		Influent	Effluent	Influent	Effluent	Influent	Effluent
Mean pH	2003	6.69	8.11	7.41	7.95	7.80	7.66
Maximum pH	2003	6.62	8.38	9.68	10.13	9.98	9.85
Minimum pH	2003	6.97	9.97	6.05	6.49	7.42	6.51
Standard Deviation	2003	6.95	8.90	0.47	1.08	0.46	1.13

The most evident trend is the high degree of diurnal variability in the effluent pH, which as noted previously, is associated with the consumption of carbon dioxide, bicarbonate and carbonate during photosynthesis by the algae community on the ATS™. 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 noted within Figure 2-58. 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.

Saunders et al. (1962) in their studies on phytoplankton productivity in the Great Lakes, related pH, alkalinity, and available carbon, based upon disassociation equations, as noted in Figure 2-59. Considering the alkalinity within the L-62 water is relatively low at about 45-65 mg/l as $CaCO_3$, the available carbon at pH 7.0 is about 18-19 mg/l, or about 80 pounds per 0.5 MGD. When the pH raises to 8.5 –9.0 at the influent to the ATS™ this value is reduced to about 50 pounds. The theoretical potential productivity therefore of the ATS™, considering algal biomass to be about 40% carbon on a dry weight basis, is about 125 pounds daily, or over the entire area of 8,311 m^2, about 6.8 g/m^2-day. Not surprisingly, this is close to what is being observed, and not far from the 9.1 g/m^2-day productivity that was projected within the preliminary engineering report as submitted prior to project initiation. It needs to be recognized that in addition to the carbon that is available within the influent, there is a dynamic factor associated with the transfer of CO_2 gas via the atmosphere. This is a complex process driven not only be temperature, pH and pressure, but also by the extent of contact between the water and the atmosphere—a consideration that is closely related to the water depth and turbulence. This is one consideration that needs to be evaluated as linear hydraulic loading rate and floway velocity increases as assessed in the S-154 Single Stage Algal Turf Scrubber® Final Report..

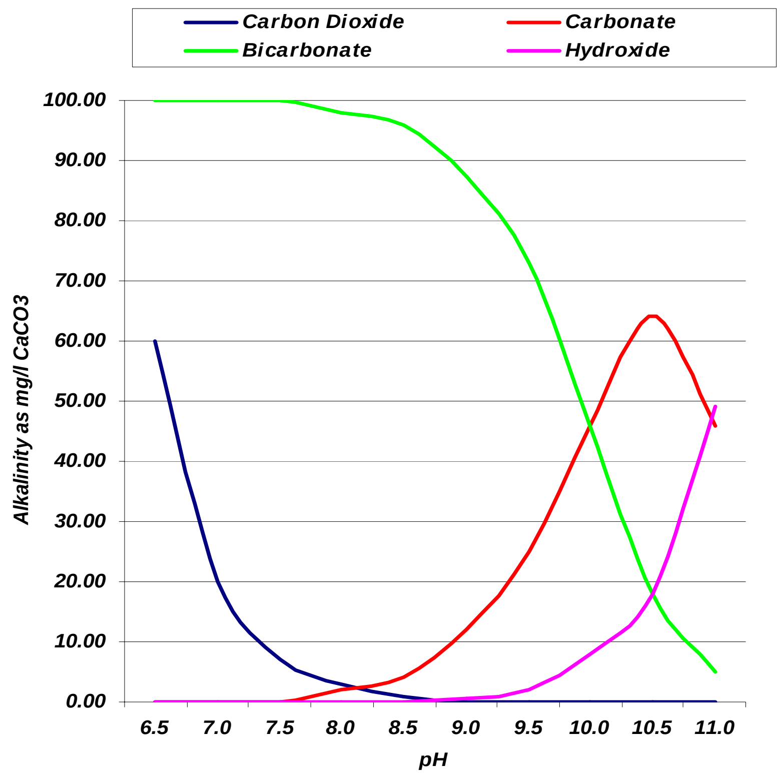


Figure 2-58: Relationship of pH to carbon dioxide, and carbonate, bicarbonate and hydroxide alkalinity

As the flow moves down the floway, the pH increases. As noted, at about pH =10.1 there must be considered to be little available carbon remaining, and accordingly, productivity in these distal reaches is reduced considerably. To reduce the potential negative influence of high pH, both in terms of toxic impacts and trace mineral availability, acid was added to the ATS™ recycled flow under the operational program associated with Quarters 1-3. Acid addition provides an immediate means of reducing pH that otherwise might be achieved through use of a effluent equalization or buffer pond prior to re-introduction of recycled flow back upon the ATS™. With the reduced pH, available carbon is increased.

At the end of the second quarter, consideration was given to several operational and design modifications to address this issue. One possibility considered is use of one of the existing WHS™ treatment units as an ATS™ effluent equalization/buffer pond or second stage WHS™. This modification would serve as a means of providing adequate retention of ATS™ effluent prior to recycling to facilitate a reduction in pH and elimination of the use of acid. The second stage WHS™ would provide the additional benefit of additional nutrient and temperature reduction. The bench scale program of a second stage WHS™, verified significant pH reduction, from about 9.5-10.0 to 6.5-7.0 during the daytime hours.

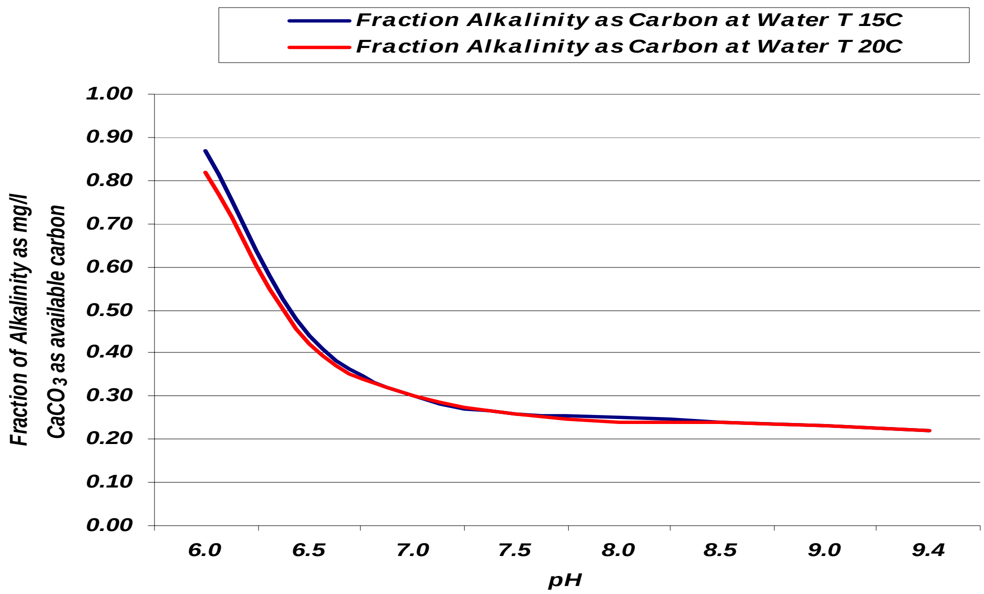


Figure 2-59: Relationship of pH to alkalinity and available carbon from Saunders et al. (1962)

While the influent pH changed little from Q1 to Q3, there is a notable increase in effluent pH during Q2, with a decline noted during Q3, particularly in October. The number of data points from the in-situ pH monitor, when the effluent pH was above10 are presented within Figure 2-60 and 2-61. There is considerable increase in June 2003, with the highest number of events being from 10:30 AM to 12:30 PM. From review of Figure 2-61 the number and frequency of events appears to be cyclical. This may be due to intermittent fluctuation in algae productivity in response to the high pH and carbon availability. This pattern may also be impacted by rainfall events and the associated drop in light intensity. The highest number of high pH in the effluent events was during June 9 and 11 and July 27, 2003 (22). The lowest period during June and July was during July 8 through 11, 2003, which is during the heaviest loss of algae biomass of the disruptive event. No pH greater than 10 was observed during Q4, however during Q5, there was a period of a few high effluent pH values observed from February 2-3 and February 9-18, 2004 (36 total samples which are taken each 30 minutes) where maximum pH was 10.35. Each of these instances occurred between the hours of 12:00 and 4:00 pm. There was no recorded pH value of 10 or greater during Q6.

Of equal importance is the pH of the influent water to the ATS™, which sets the conditions in the upper regions of the floway. As noted in Figure 2-32, the period of highest influent pH to the ATS™ was March, which corresponds to the period in which productivity problems were most notable on the ATS™. Acid addition was initiated by April. There was one day in June, specifically June 4th, when the influent pH was above 10. The ATS™ influent pH during Q4 through Q6 was typically near 6.8, coming directly and solely from the WHS™ units—recycling upon the ATS™ having been eliminated. This provided a much more stable situation within the ATS™ system in terms of pH and temperature fluctuations.

While the development of a more expansive algae mat appeared to allow capture of available carbon, the productivity remained comparatively low through Q3, perhaps attributable largely to carbon limitation as discussed. As noted, the high pH also influences the availability of essential minerals, as many cations will precipitate as salts at the higher pH levels. During the loading rate study, pH rise became less of an issue, as water was no longer being recycled through the system.

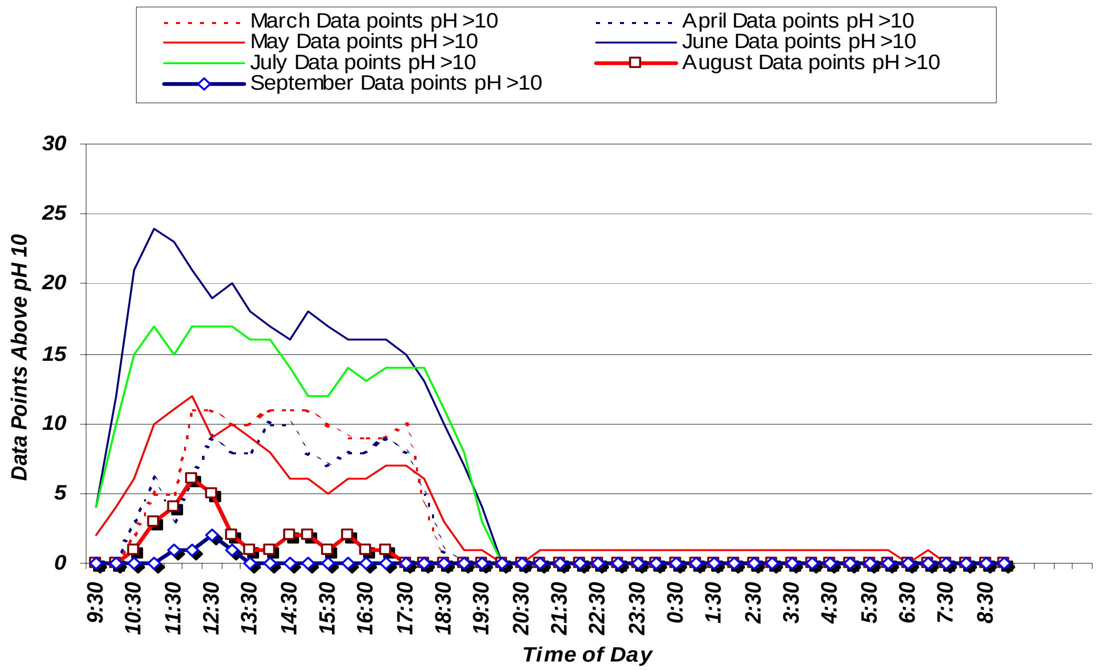


Figure 2-60: pH data points above 10.0 by time of day and month

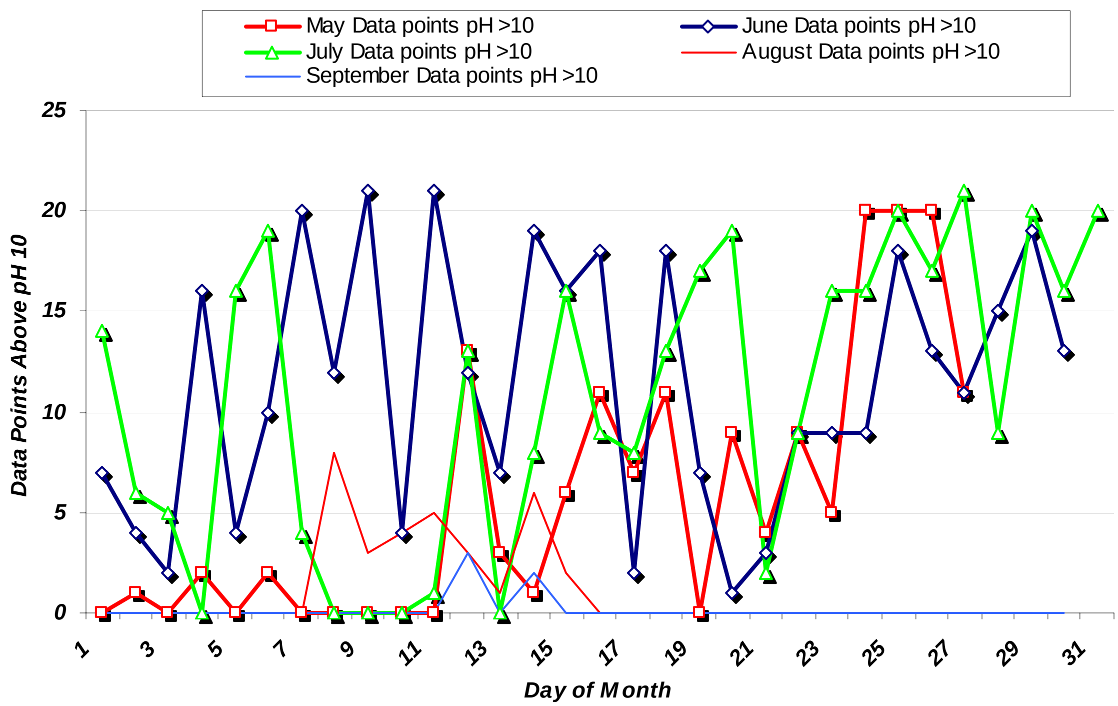


Figure 2-61: pH data points above 10.0 by day of month and month for Q2 and Q3

To correct the pH interference three options were initially considered. The first was to add a readily degradable organic substance to the WHS™, thereby increasing the carbon dioxide level and decreasing pH. It was hypothesized that the Total Organic Carbon (TOC) concentration in the L-62 water (about 30 mg/l) might be sufficient in the influent to reduce pH once it degraded in the WHS™. However, the TOC was not readily degradable, supporting a BOD_5 of only about 5 mg/l. The second strategy considered for lowering pH was to add sodium bicarbonate ($NaHCO_3$), which would, by increasing bicarbonate alkalinity result in a pH reduction while offering an additional carbon source to the algae. The third approach was to add mineral acid as hydrochloric acid (HCl) to reduce hydroxide alkalinity and thus reduce pH. The acid addition was selected because of a lower cost than bicarbonate addition. The addition of an organic compound was viewed skeptically because of the potential impact on dissolved oxygen levels in the WHS™. By early April, 20 gallons of 35% muriatic (hydrochloric) acid was added during the daylight hours to the ATS™ influent. This, in combination with a mineral supplementation program and increased hydraulic recycling, resulted in the extensive development of algae biomass during April. In June, an attempt was made to reduce the amount of acid addition from 20 gallons to 17 gallons daily. This was discontinued however, within two weeks to maintain desirable pH levels.

During the third quarter, acid addition was increased and sodium bicarbonate was added to see what influence this would have on influent pH and productivity. As noted in Figures 2-60 through 2-62, there was a noticeable reduction in pH, and based upon harvests, as presented in Section 3 and 4, and the presence of high DO levels during the daylight hours, some increased production was noted. There was no acid addition during the 4th through 6th quarters, as effluent pH was not significantly increased from influent pH due to the fact that water was not recycled through the system.

As mentioned previously, a fourth option to managing carbon limitations and pH impacts would be to have an equalization or holding pond for the ATS™ effluent prior to reintroducing recycled flow to the ATS™. In the S-154 facility, this scenario could be achieved through a retention pond such as the ATS™ borrow area. This might be done in concert with adjustments to recycle rates, nutrient loading rates, and supplementations with calcium carbonate.

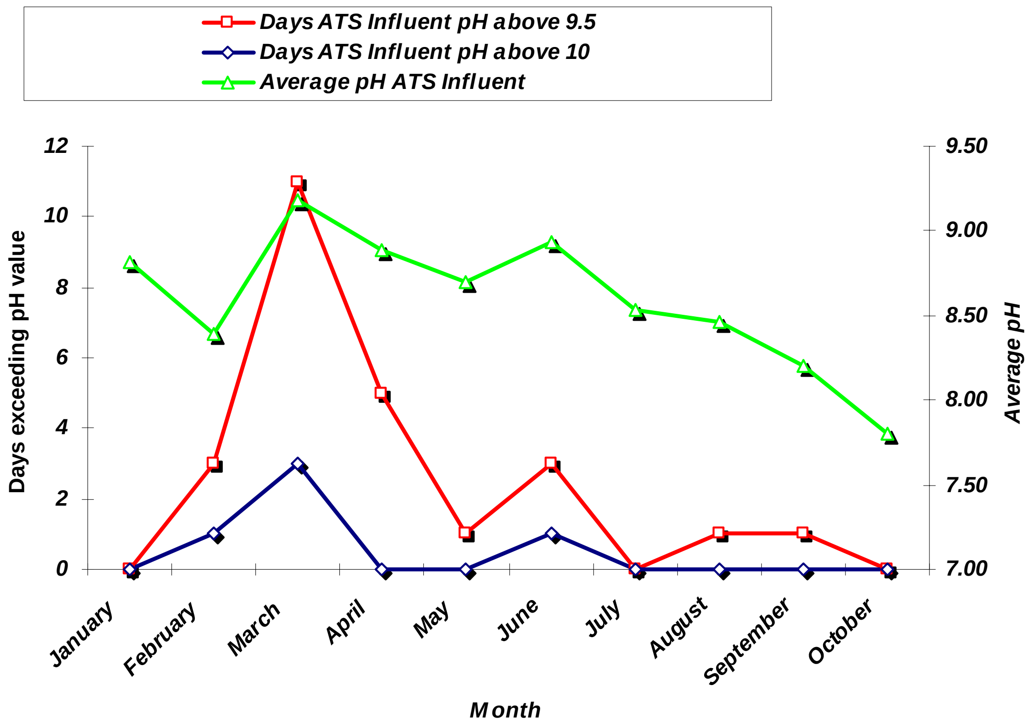


Figure 2-62: pH data points above 9.5 and 10.0 and average daytime pH ATS™ influent

SECTION 3. NUTRIENT BALANCE

IDENTIFICATION OF MEASURABLE AND IMMEASURABLE INPUTS, OUTPUTS AND STORES

The system nutrient balance can be developed using Equation 3. Within this report a balance is developed for both phosphorus and nitrogen.

$$\mathbf{I = O + \triangle S} \qquad \text{(Equation 3)}$$

Where I = inputs
O = outputs
$\triangle$S = change in internal storage

This relationship can be further expressed into measurable and immeasurable components.

$$\mathbf{I_m + I_i = O_m + O_i + \triangle S_m + \triangle S_i} \qquad \text{(Equation 4)}$$

Where the subscript **"m"** refers to measurable categories and "**i**" refers to immeasurable categories. Rearranging Equation 4, results in Equation 5.

$$\mathbf{I_m - O_m - \triangle S_m = (O_i - I_i + \triangle S_i)} \qquad \text{(Equation 5)}$$

If the left side of Equation 5 is negative, then a large immeasurable input would be suspected, such as regeneration from the sediments. If the left side of the equation is positive, the a large immeasurable output, such as ecological losses due to predation, emigration or larval emergence or change in immeasurable stores, such as biomass in other trophic compartments would be expected.

Measurable inputs for phosphorus include:

1. Phosphorus load in pounds contained within the L-62 influent to the system (P_L)
2. Phosphorus load in pounds contained within rainfall to the system (P_R)
3. Phosphorus load in pounds contained within any supplements added to the system (P_S)

Immeasurable inputs for phosphorus would include:

1. Phosphorus loads in pounds brought into the system through immigration (P_I), which would include both internal regeneration from stored sediments, and external sources such as excrement from visiting wildlife, wind blown materials, and related external activities generally outside the control of the operator. Because the system is closed from groundwater influx through a HDPE geomembrane liner, seepage inputs are considered zero, and are not included within the calculations.

Measurable outputs for phosphorus include:

1. Phosphorus load in pounds contained within the system effluent discharged from the system (P_D)
2. Phosphorus load in pounds contained within any harvested products (P_H), which include harvested water hyacinths (P_W), harvested algae removed via the Duperon Flex-Rake (P_{AR}), and algae, sediments removed by the microscreen (P_{AM}), and for Q4 through Q6, harvested algae diverted around the microscreen (P_{AD})

Immeasurable outputs for phosphorus include:

1. Phosphorus load in pounds removed through the system through either direct emigration, or through predation and grazing (P_E), which would include larvae maturation and emigration of adults (e.g. dragonfly larvae, tadpoles), movement onto the site by predators (e.g. otter, water snakes, hawks, crows) or grazers (gallinules, turkey, some wading birds), and subsequent emigration of those predators and grazers off site.

Measurable stores for phosphorus include:

1. Phosphorus load in pounds contained within the difference in the period beginning water hyacinth biomass and the period ending water hyacinth biomass ($\triangle\mathbf{S_{PW}}$).
2. Phosphorus load in pounds contained within the difference in the period beginning algae biomass and the period ending algae biomass ($\triangle\mathbf{S_{PA}}$).
3. Phosphorus load in pounds contained within material retained in the deposited sediments within the system ($\triangle\mathbf{S_{PS}}$).
4. Phosphorus load in pounds contained within the difference in that held within the system's water column –primarily within the WHS™ ($\triangle\mathbf{S_{PC}}$).

Immeasurable stores for phosphorus include:

1. Phosphorus load in pounds between the difference of period beginning and period ending of organisms retained within the system in other trophic levels outside primary producers which are not collected as part of the hyacinth biomass, e.g. animals such as fish and other vertebrates within the water column, macroinvertebrates within the water column, and other organisms that would resist being discharged from the system through either through direct discharge or loss to predation. ($\triangle\mathbf{S_{PO}}$**)**

Measurable inputs for nitrogen include:

1. Nitrogen load in pounds contained within the L-62 influent to the system (N_L)
2. Nitrogen load in pounds contained within rainfall to the system (N_R)
3. Nitrogen load in pounds contained within any supplements added to the system (N_S)

Immeasurable inputs for nitrogen include:

1. Nitrogen fixed from atmospheric nitrogen, typically through specialized algae and bacteria known as "nitrogen fixers" (N_F).
2. Nitrogen load in pounds contained brought into the system through immigration (N_I), which would include excrement from visiting wildlife, wind blown materials, and related external activities generally outside the control of the operator.

Measurable outputs for nitrogen include:

1. Nitrogen load in pounds contained within the system effluent discharged from the system (N_D)
2. Nitrogen load in pounds contained within any harvested products (N_H), which include harvested water hyacinths (N_W), harvested algae removed via the Duperon Flex-Rake (N_{AR}), and algae , sediments removed by the microscreen (N_{AM}), and for Q4 and Q5 harvested algae diverted around the microscreen (N_{AD})

Immeasurable outputs for nitrogen include:

a. Nitrogen load in pounds removed through the system through either direct emigration, or through predation and grazing (N_E), which would include the same factors as for phosphorus.
b. Nitrogen lost to the atmosphere through denitrification and ammonia volatilization (N_{DN})

Measurable stores for nitrogen include:

1. Nitrogen load in pounds contained within the difference in the period beginning water hyacinth biomass and the period ending water hyacinth biomass ($\triangle \mathbf{S_{NW}}$).
2. Nitrogen load in pounds contained within the difference in the period beginning algae biomass and the period ending algae biomass ($\triangle \mathbf{S_{NA}}$).
3. Nitrogen load in pounds contained within material retained in the deposited sediments within the system ($\triangle \mathbf{S_{NS}}$).
4. Nitrogen load in pounds contained within the difference in that held within the system's water column –primarily within the WHS™ ($\triangle \mathbf{S_{NC}}$).

Immeasurable stores for nitrogen include:

1. Nitrogen load in pounds between the difference of period beginning and period ending of organisms retained within the system in other trophic levels outside primary producers which are not collected as part of the hyacinth biomass, e.g. animals such as fish and other vertebrates within the water column, macroinvertebrates within the water column, and other organisms that would resist being discharged from the system through either through direct discharge or loss to predation. ($\triangle \mathbf{S_{NO}}$)

ASSESSMENT OF MEASURABLE INPUTS

Measurable inputs are noted in Table 3-1. In calculating the rainfall values for Q1 through Q3 an inclusion area of 5.3 acres was considered. The rainfall amount for Q1 of 10.9 inches, or 1,568,804 gallons, Q2 of 15.2 inches or 2,187,690 gallons and Q3 of 19.7 inches or 2,840,000 gallons, and phosphorus and nitrogen concentrations of 25 ppb and 60 ppb respectively, or 0.33 lbs of phosphorus and 0.79 lbs of nitrogen for Q1, 0.45 lbs of phosphorus and 1.09 lbs of nitrogen for Q2 and 0.59 lbs of phosphorus and 1.42 lbs of nitrogen for Q3. The process area was reduced to about 2.09 acres for Q4 through Q6, and rainfall was 4.6 inches (261,078 gal) for Q4, and 5.7 inches (323,510 gal) for Q5. During the sixth quarter, which includes two hurricane events, 40.8 inches of rain fell on the system (2,315,649 gal). Using the same concentration values for total phosphorus and total nitrogen of 25 ppb and 60 ppb respectively, this equates to a rain contribution of 0.054 lbs total phosphorus and 0.131 lbs total nitrogen for Q4, and 0.067 lbs total phosphorus and 0.162 lbs of total nitrogen for Q5. Quarter 6 rainfall added 0.48 lbs total phosphorus and 1.16 lbs total nitrogen.

Table 3-1: Summary of measurable nitrogen and phosphorus inputs for the period January 27, 2003 through October 18, 2004

Measurable Inputs	Phosphorus (lbs)						
	Q1	Q2	Q3	Q4	Q5	Q6	Total
Influent from L-62 (P_L)	190.17	148.71	127.83	93.70	239.98	244.10	1,044.49
Rainfall (P_R)	0.33	0.45	0.59	0.05	0.07	0.48	1.97
Supplementation (P_S)	0.44	0	0	0	0	0	0.44
TOTAL	190.94	149.16	128.42	93.75	240.05	244.58	1,046.90

Measurable Inputs	Nitrogen						
	Q1	Q2	Q3	Q4	Q5	Q6	Total
Influent from L-62 (N_L)	749.38	729.45	830.97	1,018.40	1,359.60	1,354.01	6,041.81
Rainfall (N_R)	0.79	1.09	1.42	0.13	0.16	1.16	4.75
Supplementation (N_s)	498.20	729.80	835.60	1,218.00	546.20	828.00	4,655.80
TOTAL	1,248.37	1,460.34	1,667.99	2,236.53	1,905.96	2,183.17	10,702.36

ASSESSMENT OF MEASURABLE OUTPUTS

Effluent Discharge

The effluent discharge amounts as noted previously are:

Q1 P_{D1} = 25.16 lbs ; N_{D1} = 544.38 lbs
Q2 P_{D2} = 24.87 lbs ; N_{D2} = 528.43 lbs
Q3 P_{D3}= 24.72 lbs ; N_{D3} = 628.48 lbs
Q4 P_{D4}= 42.01 lbs ; N_{D4} = 1,148.40 lbs
Q5 P_{D5}= 96.08 lbs ; N_{D5} = 1,137.10 lbs
Q6 P_{D6}= 187.30 lbs ; N_{D5} = 1,309.9 lbs

Harvested and Screened Solids

Because the system is closed from groundwater influx through a HDPE geomembrane liner, seepage outputs are considered negligible, and are not included within the calculations. The diverted harvested algae (P_{AD}) as noted for Q4 through Q6 represents algae, which passed through the rake, and was diverted around the microscreen during harvest. This diversion was necessary because of the increased hydraulic loading to nearly 700 gpm. As the microscreen has a capacity of only 350 gpm, it was necessary to divert and discharge some of these algae particles during harvest. This algae typically was small fragments and unicellular algae, such as diatoms. To quantify P_{AD}, a separate sample bottle was placed in the autosampler during harvest, and the flow during harvest documented. The diverted phosphorus and nitrogen therefore is calculated as the product of the flow segment during harvest and the concentration during this period minus the calculated effluent concentration.

As sampling is based on flow sequencing, not all samples taken during harvest were done at the same time period during harvest, and on a few occasions, sample size was inadequate to complete the analyses. Therefore a monthly average was used to represent the mean concentration of the diverted flows. Calculations of P_{AD} are shown as Table 3-3 (Note that the phosphorus and nitrogen diverted as harvest by-pass during Q4 through Q6 amount to an equivalent increase in average effluent concentration of 7.2 ppb total phosphorus and 0.06 mg/l total nitrogen).

Outputs associated with harvested and screened materials are summarized within Tables 3-2 and Table 3-3. The percent dry solids for plant tissue and microscreen residues were analyzed by HydroMentia per the approved Monitoring Plan. The microscreen residues percent solids were collected and sampled for analysis normally on a weekly basis, and laboratory analyses were performed by Midwest Laboratories on a quarterly composite sample. The diverted algae harvest is as shown in Table 3-3.

Table 3-2: Review of biomass harvest from WHS™ for the period January 27, 2003 through October 18, 2004.

	Water Hyacinth Harvest (P_W,N_W)			
Period	**Feb**	**March**	**April**	**Q1 Total**
Harvest (wet-lbs)	1711	62,415	104,716	168,842
Percent solids (%)	5.9	5.2	6.7	6.1
Harvest (dry-lbs)	100.95	3,245.58	7,015.97	10,362.50
% phosphorus dry-wt.	0.29	0.36	0.45	0.42
% nitrogen dry-wt	2.40	2.45	2.40	2.43
P (lbs)	0.29	11.68	31.57	P_{W1} =43.54
N (lbs)	2.42	79.52	168.38	N_{W1} =250.32

	Water Hyacinth Harvest (P_W,N_W)			
Period	**May**	**June**	**July**	**Q2 Total**
Harvest (wet-lbs)	75,160	68,647	82,267	226,074
Percent solids (%)	5.9	9.1	8.2	7.7
Harvest (dry-lbs)	4,434.44	6,246.88	6,745.89	17,427.21
% phosphorus dry-wt.	0.45	0.45	0.49	0.47
% nitrogen dry-wt	2.61	2.35	2.22	2.37
P (lbs)	19.95	28.11	33.05	P_{W2} = 81.11
N (lbs)	115.74	146.80	149.76	N_{W2}= 412.30

Table 3-2: Continued

	Water Hyacinth Harvest (P_W,N_W)			
Period	**August**	**September**	**October**	**Q3 Total**
Harvest (wet-lbs)	42,970	70,502	66,694	180,166
Percent solids (%)	9.70	5.40	5.74	6.55
Harvest (dry-lbs)	4,168.88	3,810.19	3,829.81	11,808.88
% phosphorus dry-wt.	0.51	0.51	0.48	0.50
% nitrogen dry-wt	2.50	2.50	2.43	2.48
P (lbs)	21.26	19.43	18.38	P_{W3} = 59.07
N (lbs)	104.22	95.25	93.07	$N_{W\ 3}$= 292.54

	Water Hyacinth Harvest (P_W,N_W)			
Period	**November**	**December**	**January**	**Q4 Total**
Harvest (wet-lbs)	41,172	43,008	41,348	125,528
Percent solids (%)	3.76	5.33	5.85	4.99
Harvest (dry-lbs)	1,548.07	2,292.33	2,418.86	6,259.26
% phosphorus dry-wt.	0.48	0.39	0.35	0.40
% nitrogen dry-wt	2.43	2.62	2.82	2.65
P (lbs)	7.43	8.94	8.47	P_{W4} =24.84
N (lbs)	37.62	60.06	68.22	N_{W4}=165.90

Table 3-2: Continued

	Water Hyacinth Harvest (P_W,N_W)				
Period	**February**	**March**	**April**	**May**	**Q5 Total**
Harvest (wet-lbs)	53,596	32,940	69,642	95,018	251,196
Percent solids (%)	4.35	4.01	4.79	3.96	4.28
Harvest (dry-lbs)	2,331.43	1,320.89	3,335.85	3,762.71	10,750.88
% phosphorus dry-wt.	0.24	0.35	0.39	0.39	0.34
% nitrogen dry-wt	1.82	2.25	2.17	2.27	2.13
P (lbs)	5.60	4.62	13.01	14.67	P_{W5} =37.90
N (lbs)	42.43	29.72	72.39	85.41	N_{W5}= 229.95

	Water Hyacinth Harvest (P_W,N_W)					
Period	**June**	**July**	**Aug**	**Sept**	**Oct**	**Q6 Total**
Harvest (wet-lbs)	88070	56375	71228	-	30700	246373
Percent solids (%)	5.28	5.80	5.33	-	5.00	5.41
Harvest (dry-lbs)	4581.43	3308.80	3749.40	-	1535.00	13174.63
% phosphorus dry-wt.	0.28	0.18	0.18	-	0.38	0.24
% nitrogen dry-wt	2.04	2.00	1.70	-	2.40	1.97
P (lbs)	12.83	5.96	6.75	-	5.83	P_{W6} =31.37
N (lbs)	93.46	66.18	63.74	-	36.84	N_{W6}=260.22

Table 3-3: Review of biomass harvests from ATS™ for the period January 27, 2003 through October 18, 2004.

	Algae Harvest Duperon Flex-Rake (P_{AR},N_{AR})				**Algae Harvest Microscreen (P_{AM},N_{AM})**			
Period	**Feb**	**March**	**April**	**Q1 Total**	**Feb**	**March**	**April**	**Q1 Total**
Harvest (wet-lbs)	147	0	3,668	3,815	395	2,557	33,537	36,489
Percent Solids (%)	5.5	-	7.6	7.5	36.2	24.8	7.1	8.7
Harvest (dry-lbs)	8.1	0	278.8	286.9	143.1	634.1	2,381.1	3,158.3
% phosphorus dry-wt.	0.42	-	0.47	0.47	0.52	0.52	0.52	0.52
% nitrogen dry-wt	4.55	-	4.55	4.55	3.22	3.22	3.22	3.22
P (lbs)	0.03		1.31	P_{AR1} =1.34	0.74	3.30	12.38	P_{AM1} =16.42
N (lbs)	0.37		12.68	N_{AR1}=13.05	4.60	20.42	76.67	N_{AM1} =101.69

	Algae Harvest Duperon Flex-Rake (P_{AR},N_{AR})				**Algae Harvest Microscreen (P_{AM},N_{AM})**			
Period	**May**	**June**	**July**	**Q2 Total**	**May**	**June**	**July**	**Q2 Total**
Harvest (wet-lbs)	8,349	19,667	2,542	30,558	647	2,373	8,555	11,575
Percent Solids (%)	6.4	5.1	5.9	5.5	5.6	3.6	16.4	13.2
Harvest (dry-lbs)	530.2	1,003.0	149.4	1,682.6	36.3	85.3	1,404.8	1,526.4
% phosphorus dry-wt.	0.49	0.56	0.70	0.53	0.47	0.47	0.47	0.47
% nitrogen dry-wt	5.20	4.94	4.46	5.20	2.40	2.40	2.40	2.40
P (lbs)	2.60	5.62	1.05	P_{AR2} =9.27	0.17	0.40	6.59	P_{AM2}=7.16
N (lbs)	27.57	49.55	6.66	N_{AR2}= 83.78	0.87	2.05	33.68	N_{AM2} =36.60

Table 3-3: Continued

	Algae Harvest Duperon Flex-Rake (P_{AR},N_{AR})				Algae Harvest Microscreen (P_{AM},N_{AM})			
Period	**Aug**	**Sept**	**Oct**	**Q3 Total**	**Aug**	**Sept**	**Oct**	**Q3 Total**
Harvest (wet-lbs)	7,261	9,294	14,382	30,937	2,997	2,677	9,452	15,126
Percent Solids (%)	5.34	4.46	5.09	4.96	3.49	2.36	2.04	2.38
Harvest (dry-lbs)	387.8	414.5	732.4	1,534.7	104.5	62.9	193.1	360.5
% phosphorus dry-wt.	0.66	0.60	0.53	0.58	0.50	0.50	0.50	0.50
% nitrogen dry-wt	4.83	4.83	4.46	4.64	3.37	3.37	3.37	3.37
P (lbs)	2.56	2.49	3.87	P_{AR3} = 8.92	0.52	0.31	0.97	P_{AM3}= 1.80
N (lbs)	18.73	20.02	32.67	N_{AR3}= 71.42	3.52	2.12	6.51	N_{AM3}= 12.14

	Algae Harvest Duperon Flex-Rake (P_{AR},N_{AR})				Algae Harvest Microscreen (P_{AM},N_{AM})			
Period	**Nov**	**Dec**	**Jan**	**Q4 Total**	**Nov**	**Dec**	**Jan**	**Q4 Total**
Harvest (wet-lbs)	7,289	6,126	4,842	18,259	1,765	1,368	1,240	4,373
Percent Solids (%)	4.26	4.76	6.13	5.09	7.85	7.62	7.13	7.54
Harvest (dry-lbs)	309.5	291.6	296.8	897.9	138.6	104.2	88.4	331.2
% phosphorus dry-wt.	0.59	0.48	0.52	0.53	1.15	0.39	0.39	0.64
% nitrogen dry-wt	4.66	3.17	3.91	3.91	3.37	2.58	2.58	2.84
P (lbs)	1.82	1.40	1.54	P_{AR4} =4.76	1.59	0.40	0.35	P_{AM4}= 2.34
N (lbs)	14.42	9.24	11.60	N_{AR4}= 35.26	4.67	2.69	2.31	N_{AM4}= 9.67

Table 3-3: Continued

Algae Harvest Discharge (P_{AD},N_{AD})			
***no discharged harvest in Nov.**	**Dec**	**Jan**	**Q4 Total**
Diverted Volume (gal)	320,000	330,000	650,000
Mean TP (mg/L)	1.373	0.928	1.12
Mean TN (mg/L)	7.01	10.84	9.16
P (lbs)	3.66	2.55	P_{AD4}= 6.21
N (lbs)	18.71	29.83	N_{AD4}= 48.54

	Algae Harvest Duperon Flex-Rake (P_{AR},N_{AR})					Algae Harvest Microscreen (P_{AM},N_{AM})				
Period	**Feb**	**Mar**	**Apr**	**May**	**Q5 Total**	**Feb**	**Mar**	**Apr**	**May**	**Q5 Total**
Harvest (wet-lbs)	3,404	8,121	3,906	5,103	20,534	500	938	947	1,285	3,670
Percent Solids (%)	5.36	3.95	5.24	4.37	4.64	7.36	6.30	6.08	5.32	6.16
Harvest (dry-lbs)	182.5	320.8	204.7	233.0	941.0	36.8	59.1	57.6	68.4	221.9
% phosphorus dry-wt.	0.43	0.52	0.61	0.46	0.51	0.39	0.50	0.50	0.61	0.50
% nitrogen dry-wt	3.90	3.79	3.69	3.73	3.78	2.58	2.24	2.24	1.90	2.24
P (lbs)	0.78	1.67	1.25	1.08	P_{AR5} = 4.78	0.14	0.30	0.29	0.42	P_{AM5} = 1.15
N (lbs)	7.12	12.16	7.55	8.69	N_{AR5} =35.52	0.94	1.34	1.29	1.29	N_{AM5} = 4.86

Table 3-3: Continued

Algae Harvest Discharge (P_{AD},N_{AD})					
	Feb	**Mar**	**Apr**	**May**	**Q5 Total**
Diverted Volume (gal)	240,000	370,000	260,000	380,000	1,250,000
Mean TP (mg/L)	0.740	0.845	0.365	0.78	0.68
Mean TN (mg/L)	8.39	3.62	2.68	7.47	5.45
P (lbs)	1.48	2.61	0.79	2.47	P_{AD4}= 7.35
N (lbs)	16.79	11.17	5.81	23.67	N_{AD4}= 57.44

	Algae Harvest Duperon Flex-Rake (P_{AR},N_{AR})						**Algae Harvest Microscreen (P_{AM},N_{AM})**					
Period	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Q6 Total**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Q6 Total**
Harvest (wet-lbs)	716.0	1,096.0	720.0	217.0	370.0	3,119.0	390.0	303.0	190.0	50.0	25.0	958.0
Percent Solids (%)	4.27	5.97	6.11	6.20	5.61	5.36	4.75	5.15	5.69	5.29	5.26	5.16
Harvest (dry-lbs)	33.45	54.26	45.34	13.45	20.76	167.26	18.56	15.81	10.71	2.65	1.31	49.04
% phosphorus dry-wt.	0.28	0.34	0.50	0.94	0.94	0.47	0.36	0.24	0.24	0.24	0.24	0.28
% nitrogen dry-wt	2.05	4.14	4.21	3.49	3.49	3.40	2.53	1.87	1.87	1.87	1.87	2.07
P (lbs)	0.09	0.18	0.23	0.13	0.20	P_{AR6} = 0.82	0.07	0.04	0.03	0.01	0.00	P_{AM5} = 0.14
N (lbs)	0.69	2.24	1.91	0.47	0.72	N_{AR6} = 6.03	0.47	0.30	0.20	0.05	0.02	N_{AM5} =1.04

Table 3-3: Continued

Algae Harvest Discharge (P_{AD},N_{AD})						
	Jun	Jul	Aug	Sept	Oct	Q6 Total
Diverted Volume (gal)	110,000	68,889	50,000	20,000	20,000	268,889
Mean TP (mg/L)	0.39	0.21	0.65	2.69	1.44	0.691
Mean TN (mg/L)	3.71	2.15	3.34	12.36	0.85	3.742
P (lbs)	0.43	0.13	0.29	0.45	0.24	P_{AD4}= 1.53
N (lbs)	5.11	2.01	2.43	2.34	0.50	N_{AD4}= 12.40

Total Measurable outputs are summarized within Table 3-4.

Table 3-4: Summary of measurable outputs

	PHOSPHORUS lbs					
Quarter	P_D (lbs)	Pw (lbs)	P_{AR} (lbs)	P_{AM} (lbs)	P_{AD} (lbs)	Total Measurable Outputs (O_{PM}) (lbs)
Q1	25.10	43.54	1.34	16.42	-	86.40
Q2	24.87	81.11	9.27	7.16	-	122.41
Q3	24.72	59.07	8.92	1.80	-	94.51
Q4	42.01	24.84	4.76	2.34	6.21	80.16
Q5	46.08	37.90	4.78	1.15	7.35	97.26
Q6	187.30	31.37	0.84	0.14	1.53	221.18
Total	350.08	277.83	29.91	29.01	15.09	701.92

	NITROGEN lbs					
Quarter	N_D (lbs)	Nw (lbs)	N_{AR} (lbs)	N_{AM} (lbs)	N_{AD} (lbs)	Total Measurable Outputs (O_{PM}) (lbs)
Q1	544.38	250.32	13.05	101.69	-	909.44
Q2	528.43	412.30	83.78	36.60	-	1,061.11
Q3	628.48	292.54	71.42	12.14	-	1,004.58
Q4	1,148.40	165.90	35.26	9.67	48.54	1,407.77
Q5	1,137.10	229.95	35.52	4.86	57.44	1,464.87
Q6	1,309.90	260.22	6.03	1.04	12.40	1,589.59
Total	5,296.69	1,611.23	245.06	166.00	118.38	7,437.36

ASSESSMENT OF MEASURABLE STORES

Biomass Standing Crop

The change in stores for the hyacinth biomass ($\triangle S_{PW}$, $\triangle S_{NW}$) is noted in Table 3-5. A moisture value for whole plants as measured during in-situ sampling is assumed to be 5%. This is consistent with literature information. On 12/9/04, during the fourth quarter, the north treatment cell (WHS™-North) was taken off line, and the initial standing crop at the beginning of the fifth quarter was set as the standing crop within the south treatment cell (WHS™-South). Therefore, in Table 3-5, the end of Q4 standing crop, which is defined as the standing crop in WHS™-South, plus the standing crop in the WHS™-North on 12/9/04, is not used as the initial standing crop for Q5. Rather, the initial standing crop for Q5 is the standing crop in WHS™-South only at the end of Q4.

To assess weekly changes in algal standing crop as a measure of algal productivity, clip plots were monitored weekly throughout Q1. To simulate algal production on the weekly harvested ATS™, it was determined that removal of biomass from the clip plot should emulate a typical harvest event, thus a portion of the standing crop was not collected. At the end of Q1, a sample event to determine total algal standing crop was not conducted. It was hopeful that a reasonable determination of total algal standing crop could be conducted at the end of Q2. However, the disruptive event eliminated a major portion of the algae crop, and recovery was just beginning by early August.

Based on measurements of algal productivity during the final week of Q1, a determination of algal biomass was made. Algal productivity for the week ending May 5, 2003 as represented by the combination of microscreen harvest and the Flex-Rake harvest, was 215 dry-lbs for the Flex-Rake at 0.47% phosphorus and 4.55% nitrogen, and approximately 791 dry-lbs for the microscreen at 0.52% phosphorus and 3.22% nitrogen or a total of 1006 dry-lbs weekly at 0.51% phosphorus and 3.22% nitrogen. Within the Preliminary Engineering report, the ATS™ modeling was done assuming a specific growth rate, **m** of 0.20/day, which represents growth in limited nutrient concentrations, as algal communities often are characterized by maximum growth rates, μ_{max} of over 1.0/day. If this rate is used in the first order growth rate equation, $Z_t = Z_o e^{\mu t}$ where Z_t and Z_0 are the standing crop biomass, and t is time in days. This can be reduced to $(Z_0+1006) = Z_o e^{\mu t}$

Using t =7 days, Z_o is calculated as 329 dry pounds as the standing crop. As noted in Figure 3-1, when growth rate is set as the independent variable, there is a logarithmic decrease in standing crop. With nutrient and carbon limitations and pH impacts, it is expected that growth rates will be no more than 0.35/day, and possibly as low as 0.10/day, setting the range of standing crop from 95 to 992 dry pounds of biomass.

Table 3-5: Change in nutrient storage within the WHS™ for the period January 27, 2003 through October 18, 2004.

	Water Hyacinths							
Period	**Begin Quarter1**	**End Quarter 1**	**End Quarter 2**	**End Quarter3**	**Difference Q1**	**Difference Q2**	**Difference Q3**	**Difference Q1-Q3**
Standing Crop (wet-lbs)	185,480	400,460	282,960	401,020	214,980	-117,500	118,060	215,540
Percent Solids (%)	5	5	5	5	5	5	5	5
Standing Crop (dry-lbs)	9,274	20,023	14,148	20,051	10,749	-5,875	5,903	10,777
% phosphorus dry-wt.	0.29	0.45	0.47	0.48	-	-	-	-
% nitrogen dry-wt	2.40	2.40	2.37	2.43	-	-	-	-
P (lbs)	26.89	90.10	66.50	96.24	$\triangle S_{PW1}$ = 63.21	$\triangle S_{PW2}$ = -23.60	$\triangle S_{PW3}$ = 29.74	$\triangle S_{PWT}$ = 69.35
N (lbs)	222.57	480.55	335.31	487.24	$\triangle S_{NW1}$ = 257.98	$\triangle S_{NW2}$ = -145.24	$\triangle S_{NW2}$ = 151.93	$\triangle S_{NWT}$ = 264.67

Water Hyacinths									
Period	**Begin Quarter 4**	**End Quarter4**	**Begin Quarter 5**	**End Quarter 5**	**End Quarter 6**	**Difference Q4**	**Difference Q5**	**Difference Q6**	**Difference Q4-Q6**
Standing Crop (wet-lbs)	401,029	347,543	181,798	211,791	157,604	-53,486	82,886	-54,187	-24,194
Percent Solids (%)	5	5	5	5	5	5	5	5	5
Standing Crop (dry-lbs)	20,051	17,377	9,090	10,590	7,880	-2,674	4,144	2,710	1,210
% phosphorus dry-wt.	0.48	0.40	0.40	0.34	0.24	-	-	-	-
% nitrogen dry-wt	2.43	2.62	2.62	2.13	1.97	-	-	-	-
P (lbs)	96.25	69.51	36.36	36.00	18.91	$\triangle S_{PW4}$ = -26.74	$\triangle S_{PW5}$ = 0.36	$\triangle S_{PW6}$ = -17.09	$\triangle S_{PWT}$ = -17.45
N (lbs)	487.25	455.28	238.16	225.57	155.24	$\triangle S_{NW4}$ = -31.97	$\triangle S_{NW5}$ = -12.59	$\triangle S_{NW6}$ = -70.33	$\triangle S_{NWT}$ = -82.92

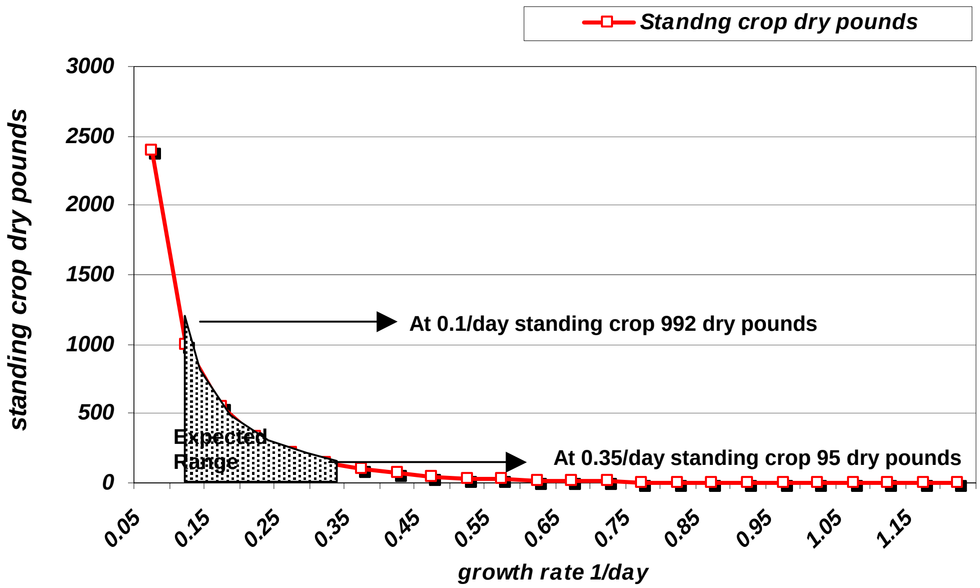


Figure 3-1: Projected algal standing crop with varying growth rate

Projections of range can now be made regarding $\Delta \mathbf{S_{PA}}$ and $\Delta \mathbf{S_{NA}}$, assuming the stores at the period beginning are zero:

$$0.50 \text{ lbs} < \Delta \mathbf{S_{PA}} < 5.0 \text{ lbs}$$
$$2.3 \text{ lbs} < \Delta \mathbf{S_{NA}} < 35.0 \text{ lbs}$$

From this, it is evident that the change in nutrient stores within the algal standing crop is not as influential as with the hyacinth crop. For Q2, the standing crop was sloughed during the disruptive event and recovered as harvest within the rake and microscreen. For Q3, there was considerable recovery of the standing crop, and the standing crop gain was assumed to be to the beginning Q2 level of 2.8 lbs-P and 19.15 lbs-N. For Q4 and Q5 the change in standing crop was assumed to be the difference between the ending and beginning estimated biomass based upon the grid measurements. For Q4, $\Delta \mathbf{S_{PA}}$ = -1.14 lbs, $\Delta \mathbf{S_{NA}}$ = -9.35**.** For Q5, $\Delta \mathbf{S_{PA}}$ = 0.07 lbs, $\Delta \mathbf{S_{NA}}$ = 0.95 lbs.

The main ATS™ flow way was moved during Q6, resulting in a net decrease in algal biomass. However, due to increased influent nutrient concentrations, actual phosphorus and nitrogen content within the biomass storage increased slightly ($\Delta \mathbf{S_{PA}}$ = 0.61 lbs, $\Delta \mathbf{S_{NA}}$ =1.07).

Water Column

Changes in nutrient stores within the WHS™ water column ($\Delta \mathbf{S_{PC}}$, $\Delta \mathbf{S_{NC}}$) can be estimated by assuming the concentration within the plug flow system is the average between influent (including supplementation) and effluent concentrations. The calculated values are noted in Table 3-6.

Table 3-6: Changes in nutrient stores within the WHS™ water column for the period January 27, 2003 through October 18, 2004.

	Nutrient stores within Water Column									
	Begin Quarter (1/27/03)		End Quarter 1 (5/5/03)		End Quarter 2 (8/4/03)		Difference Q1		Difference Q2	
Water Volume (gallons)	2,919,000		2,985,000		2,950,000					
	P	N	P	N	P	N	P	N	P	N
Influent concentration (mg/l)	0.464	2.66	0.748	4.19	0.194	3.87	0.284	1.53	-0.590	-0.32
Effluent concentration (mg/l)	0.130	1.72	0.043	1.87	0.190	1.20	0.087	0.15	0.147	-0.67
Mean concentration within WHS™ (mg/l)	0.297	2.19	0.395	3.92	0.192	2.54	0.098	1.73	-0.203	-1.38
Nutrient (lbs)	7.23	52.31	9.83	97.59	4.72	62.49	ΔS_{PC1} 2.60	ΔS_{NC1} 45.28	ΔS_{PC2} -5.11	ΔS_{NC2} -35.10

	Nutrient stores within Water Column					
	Begin Quarter 3 (8/4/03)		End Quarter 3 (11/3/03)		Difference Q3	
Water Volume (gallons)	2,950,000		2,985,000			
	P	N	P	N	P	N
Influent concentration (mg/l)	0.194	3.87	0.304	2.40	0.110	-1.47
Effluent concentration (mg/l)	0.190	1.20	0.160	3.49	-0.03	2.29
Mean concentration within WHS™ (mg/l)	0.192	2.54	0.232	2.94	-0.040	0.40
Nutrient (lbs)	4.72	62.49	5.78	73.19	ΔS_{PC3} 1.06	ΔS_{NC3} 10.7

Table 3-6: Continued

	Nutrient stores within Water Column											
	End Quarter 3 (11/3/03)		**End Quarter 4 (1/26/04)**		**Begin Quarter 5 (1/26/04)**		**End Quarter 5 (5/31/04)**		**Total Difference Quarter 4**		**Total Difference Quarter 5**	
Water Volume (gallons)	**2,950,000**		**2,985,000**		**1,806,739**		**1,969,247**					
	P	**N**	**P**	**N**	**P**	**N**	**P**	**N**	**P**	**N**	**P**	**N**
Influent concentration (mg/l)	0.304	2.40	0.11	2.53	0.11	2.53	0.31	3.49	-0.191	0.13	0.192	0.96
Effluent concentration (mg/l)	0.160	3.49	0.09	2.76	0.09	2.76	0.11	1.30	-0.050	-0.073	0.020	-1.40
Mean concentration within WHS™ (mg/l)	0.232	2.94	0.10	2.65	0.10	2.65	0.21	2.40	-0.013	-0.29	0.106	-0.25
Nutrient (lbs)	5.78	73.19	2.54	65.97	**1.54**	**39.93**	**3.42**	**39.42**	ΔS_{PCT} -3.24	ΔS_{NCT} -7.22	ΔS_{PCT} 4.96	ΔS_{NCT} -0.51

	Nutrient stores within Water Column					
	Begin Quarter 6 (6/1/04)		**End Quarter 6 (10/18/04)**		**Difference Q6**	
Water Volume (gallons)	**1,969,247**		**1,958,627**			
	P	**N**	**P**	**N**	**P**	**N**
Influent concentration (mg/l)	0.305	3.49	1.08	2.15	0.78	-1.34
Effluent concentration (mg/l)	0.110	1.30	0.96	3.11	0.85	1.81
Mean concentration within WHS™ (mg/l)	0.208	2.40	1.02	2.63	0.81	0.23
Nutrient (lbs)	3.42	39.42	16.67	42.98	ΔS_{PC3} 13.25	ΔS_{NC3} 3.56

Sediment Stores

The change in sediment stores within the WHS™ were calculated based upon data collected from sediment collection traps placed in both WHS™ treatment units. Four weighted five-gallon open containers were placed within the ponds at the beginning of Q1. The capture area of the sediment trap was 0.55 square feet. The applied WHS™ treatment area was set at 2.5 acres (except for Q5, Q6 and part of Q4, when the area was reduced to 1.25 acres.) At the end of Q1, the sediment collection traps were recovered and then reset, and this process repeated at the end of each subsequent quarter. Collected sediment was recorded both as settled depth and dry weight. Samples were then collected, composited and sent to Midwest Laboratories for analysis. The collected sediments were composed of fine flocculent organic material and some semi-decomposed fibrous water hyacinth root material. The results are noted in Table 3-7.

Table 3-7: Changes in nutrient stores within the WHS™ sediments for the period January 27, 2003 through October, 2004.

	Q1 Nutrient stores within Sediment			
	Depth (inches)	**Dry weight (g)**	**P (%)**	**N (%)**
Collection Chamber #1	0.65	19.4	-	-
Collection Chamber #2	0.40	16.0	-	-
Collection Chamber #3	0.33	23.9	-	-
Mean	0.46	19.8	-	-
Composite %	-	-	0.31	0.18
Quarterly deposition Lbs	Sediments 8,795 dry lbs		$\triangle \mathbf{S}_{PS1}$ = 27.26	$\triangle \mathbf{S}_{NS1}$ = 15.83

	Q2 Nutrient stores within Sediment			
	Depth (inches)	**Dry weight (gs)**	**P (%)**	**N (%)**
Collection Chamber #1	1.22	22.3	-	-
Collection Chamber #2	1.22	25.5	-	-
Collection Chamber #3	1.10	20.4	-	-
Mean	1.18	22.7	-	-
Composite %	-	-	0.68	2.47
Quarterly deposition Lbs	Sediments 9,900 dry lbs		$\triangle \mathbf{S}_{PS2}$ 67.32	$\triangle \mathbf{S}_{NS2}$ 244.53

Table 3-7: Continued

	Q3 Nutrient stores within Sediment			
	Depth (inches)	**Dry weight (gms)**	**P**	**N**
Collection Chamber #1	0.71	24.1	-	-
Collection Chamber #2	1.18	31.1	-	-
Collection Chamber #3	0.71	18.5	-	-
Mean	0.87	24.6	-	-
Composite %	-	-	0.35	2.25
Quarterly deposition lbs	Sediments 10,728 dry lbs		$\triangle S_{PS3}$ 37.55	$\triangle S_{NS3}$ 241.38

	Q4 Nutrient stores within Sediment			
	Depth (inches)	**Dry weight (gs)**	**P (%)**	**N (%)**
Collection Chamber #1	0.28	19.6		
Collection Chamber #2	0.16	14.0		
Collection Chamber #3	0.25	11.7		
Mean	0.23	15.08		
Composite %			0.57	1.84
Quarterly deposition lbs	Sediments 3,651 dry lbs		$\triangle S_{PS4}$ 20.81	$\triangle S_{NS2}$ 67.17

Table 3-7 Continued

	Q5 Nutrient stores within Sediment			
	Depth (inches)	**Dry weight (g)**	**P**	**N**
Collection Chamber #1	0.30	20.3	-	-
Collection Chamber #2	0.20	19.0	-	-
Mean	0.25	19.6	-	-
Composite %	-	-	0.61	1.90
Quarterly deposition lbs	Sediments 3,272dry lbs		$\triangle S_{PS5}$ 19.96	$\triangle S_{NS5}$ 62.17

	Q6 Nutrient stores within Sediment				**Total Q4-Q6**			
	Depth (inches)	**Dry weight (g)**	**P**	**N**	**Depth (inches)**	**Dry weight (g)**	**P**	**N**
Collection Chamber #1	2.04	159	-	-	2.63	198.9		
Collection Chamber #2	1.10	66.7	-	-	1.46	99.7		
Mean	1.57	112.9	-	-	2.04	149.3		
Composite %	-	-	0.44	1.86	-	-	0.54	1.87
Quarterly deposition lbs	Sediments 18,817 dry lbs		$\triangle S_{PS6}$ 82.80	$\triangle S_{NS6}$ 350.01	Total Sediments dry lbs: 25,939		Total $\triangle S_{PST}$ 123.21	Total $\triangle S_{NST}$ 473.35

Summary of Measurable Change in Stores

A summary of measurable change in stores is provided as Table 3-8.

Tale 3-8: Summary of measurable change in stores

Phosphorus					
lbs	ΔS_{PW}	ΔS_{PA}	ΔS_{PC}	ΔS_{PS}	Total Measurable Stores (ΔS_{PM})
Q1	63.21	2.80	2.60	27.26	95.87
Q2	-23.60	-2.80	-5.11	67.32	35.81
Q3	29.74	2.80	1.06	37.55	71.15
Q4	-26.74	-1.14	-3.24	20.81	-10.31
Q5	0.36	0.07	4.96	19.96	25.35
Q6	-17.09	0.61	13.25	82.80	79.57
Total	25.88	2.34	13.52	255.70	297.44

Nitrogen					
Lbs	ΔS_{NW}	ΔS_{NA}	ΔS_{NC}	ΔS_{NS}	Total Measurable Stores (ΔS_{NM})
Q1	257.98	19.15	45.28	15.83	338.24
Q2	-145.24	-19.15	-35.10	244.53	45.04
Q3	151.93	19.15	10.70	241.38	423.16
Q4	-31.97	-9.35	-7.22	67.17	18.63
Q5	-12.59	0.95	-0.51	62.17	50.02
Q6	-70.33	1.07	3.56	350.01	284.31
Total	149.78	11.82	16.71	981.09	1,159.40

SUMMATION OF MEASURABLE QUANTITES

Noted within Table 3-9 is a summation of the measured inputs, outputs and change in stores, per Equation 5.

Table 3-9: Summation of measurable quantities

Phosphorus				
lbs	Measurable Inputs I_{MP}	Measurable Outputs O_{MP}	Measurable Change in Stores $\triangle S_{MP}$	**(EQUATION 5)** $I_{MP}-O_{MP}-\triangle S_{PM} = O_{IP}-I_{IP}+\triangle S_{IP}$
Q1	190.94	86.40	95.87	8.67
Q2	149.16	122.41	35.81	-9.06
Q3	128.42	94.51	71.15	-37.24
Q1 through Q3	**468.52**	**303.32**	**202.83**	**-37.63**
Q4	93.75	80.16	-10.31	23.90
Q5	240.05	97.26	25.35	117.44
Q6	244.58	221.18	79.57	-56.17
Q4 through Q6	**578.38**	**398.60**	**94.61**	**85.17**
Total POR	**1,046.90**	**701.92**	**297.44**	**48.46**

Nitrogen				
lbs	Measurable Inputs I_{MN}	Measurable Outputs O_{MN}	Measurable Change in Stores $\triangle S_{PM}$	**(EQUATION 5)** $I_{MN}-O_{MN}-\triangle S_{MN} = O_{IN}-I_{IN}+\triangle S_{IN}$
Q1	1,248.37	909.44	338.24	0.69
Q2	1,460.34	1,061.11	45.04	354.19
Q3	1,667.99	1,004.58	423.16	240.25
Q1 through Q3	**4,376.70**	**2,975.13**	**806.44**	**595.13**
Q4	2,236.53	1,407.77	18.63	810.13
Q5	1,905.96	1,464.87	50.02	391.07
Q6	2,183.17	1,589.59	284.31	309.27
Q4 through Q6	**6,325.66**	**4,462.23**	**352.96**	**1,510.47**
Total POR	**10,702.36**	**7,437.36**	**1,159.40**	**2,105.60**

NUTRIENT BALANCE

As noted in Table 3-6, when the final column (Equation 5) is negative, the implication is that there is a significant net input from an immeasurable source. While this could include immigration or a negative change in immeasurable stores, it is likely that in the case of phosphorus, the source is regeneration from the sediments. For nitrogen this value could also include nitrogen fixation, although there are no such negative values for nitrogen, indicating that fixation, if it does occur, is minimal when compared to denitrification and ammonia volatilization. These negative values are considered to be “net immeasurable inputs”, and are added to the input tabulation, as noted in Figure 3-2 and 3-5.

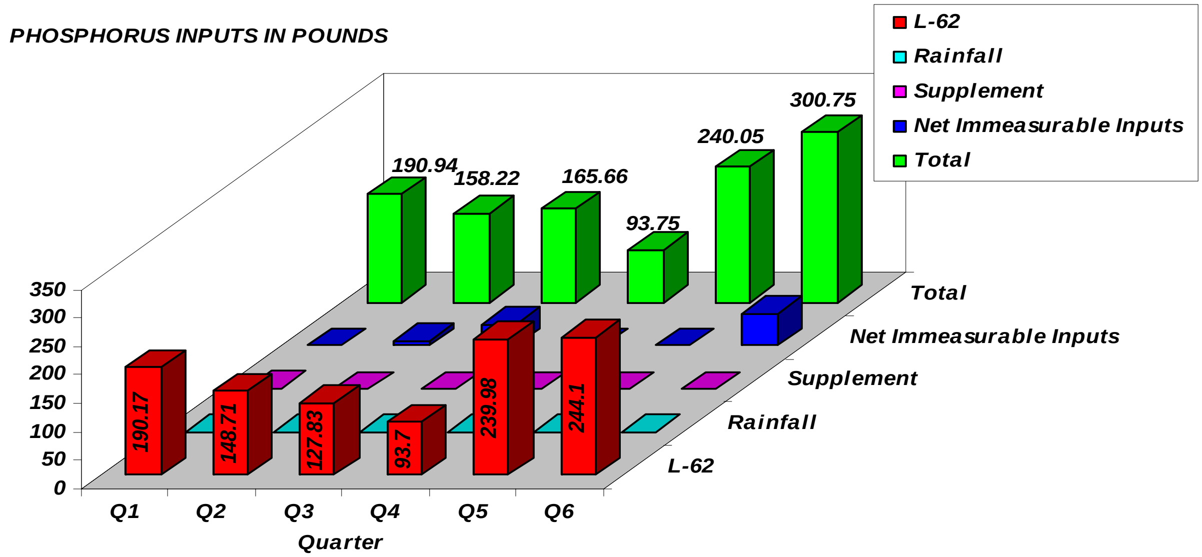


Figure 3-2: Phosphorus inputs for POR

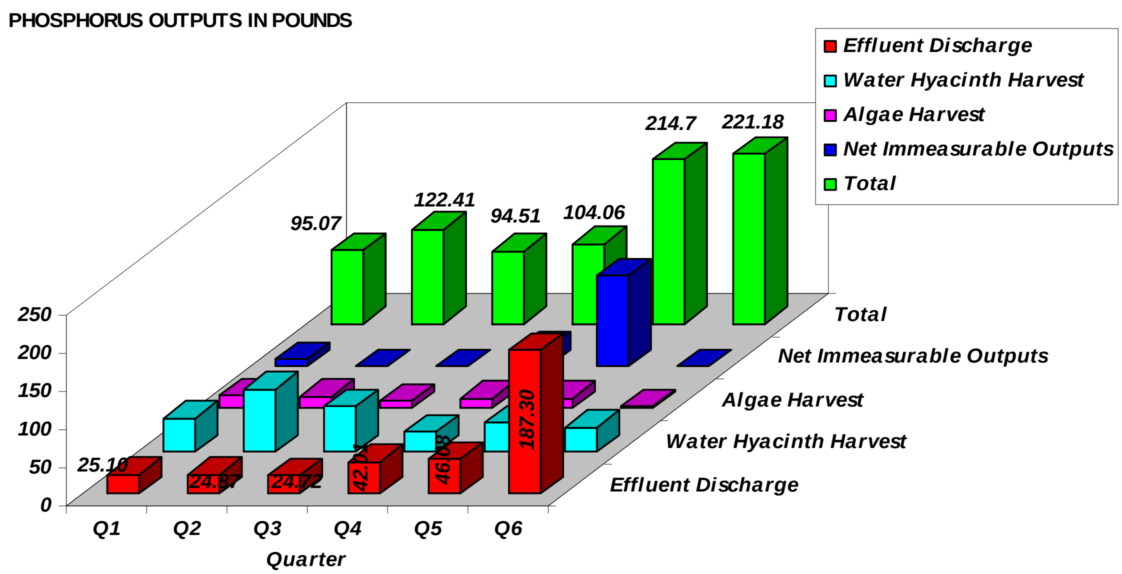


Figure 3-3: Phosphorus outputs for POR.

When the final column is positive, the implication is that there is an immeasurable output, such as emigration or a positive change in internal stores, or in the case of nitrogen, denitrification and ammonia volatilization. These positive values are noted as "net immeasurable outputs" as noted in Figure 3-3 and 3-6.

The net change in stores, as shown in Figures 3-4 and 3-7, are positive for accumulated sediments, but vary from positive to negative for the standing crops and the stored nutrients within the water column. A nutrient balance is seen by subtracting the outputs and change in stores from the inputs.

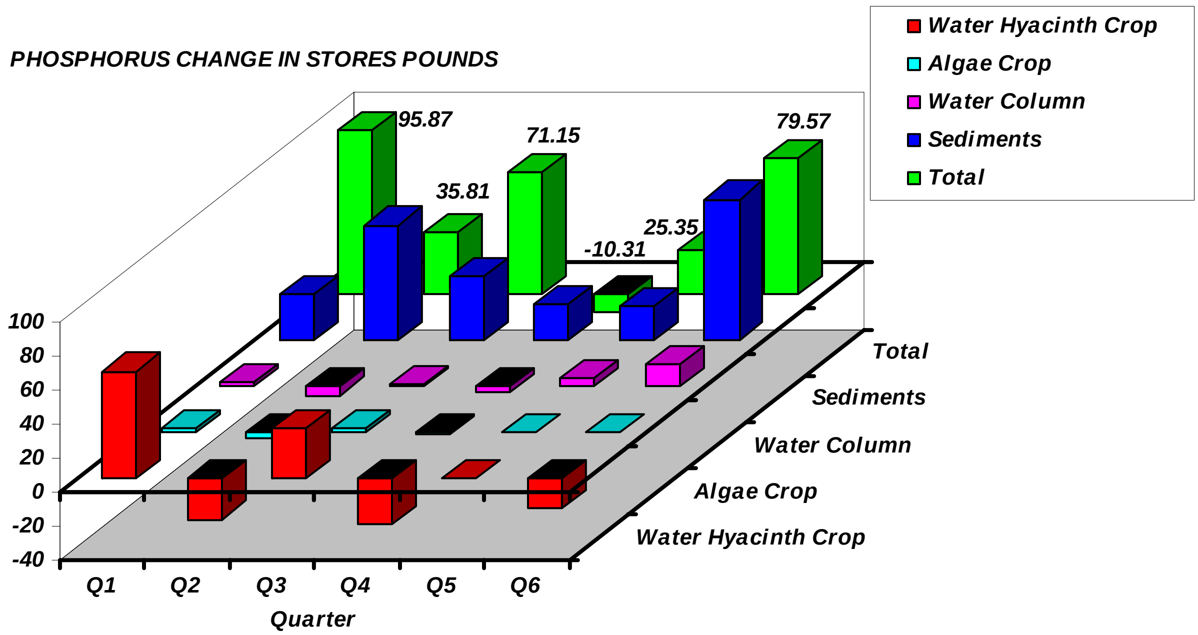


Figure 3-4: Phosphorus change in stores for POR

Of the immeasurable quantities within the phosphorus budget, the role of sediment regeneration is likely the most relevant as a phosphorus source. For three of the six quarters, there was noted a significant input from what is presumed to be sediment regeneration—9.06 lbs for Q2, 37.24 lbs for Q3 and 56.17 lbs for Q6. However, for the full POR there was still a net gain in immeasurable outputs of phosphorus (48.46 lbs), indicating that some other phenomenon was involved in phosphorus reduction, and its influence more than off-set the impacts of sediment regeneration. This immeasurable phosphorus output of 48.46 lbs for the POR however, represents only 7% of the total 694.41 pounds of phosphorus removed from L-62, which means only 7% of the removed phosphorus is unaccounted for from monitored sources. These immeasurable sources could be related to general error range associated with data collection, or with other ecological processes, including larval emergence, predation, and emigration.

With nitrogen, the net immeasurable outputs are significantly larger as projected, and there was no net immeasurable inputs noted for any of the six quarters. The net immeasurable outputs for nitrogen amounted to 2,105.60 lbs, or 39% of the nitrogen removed as determined as the difference between all measurable input sources and nitrogen load within the effluent to L-62. This is typical of what has been experienced in MAPS systems, particularly WHS™ systems, where denitrification accounts for much of the nitrogen removal.

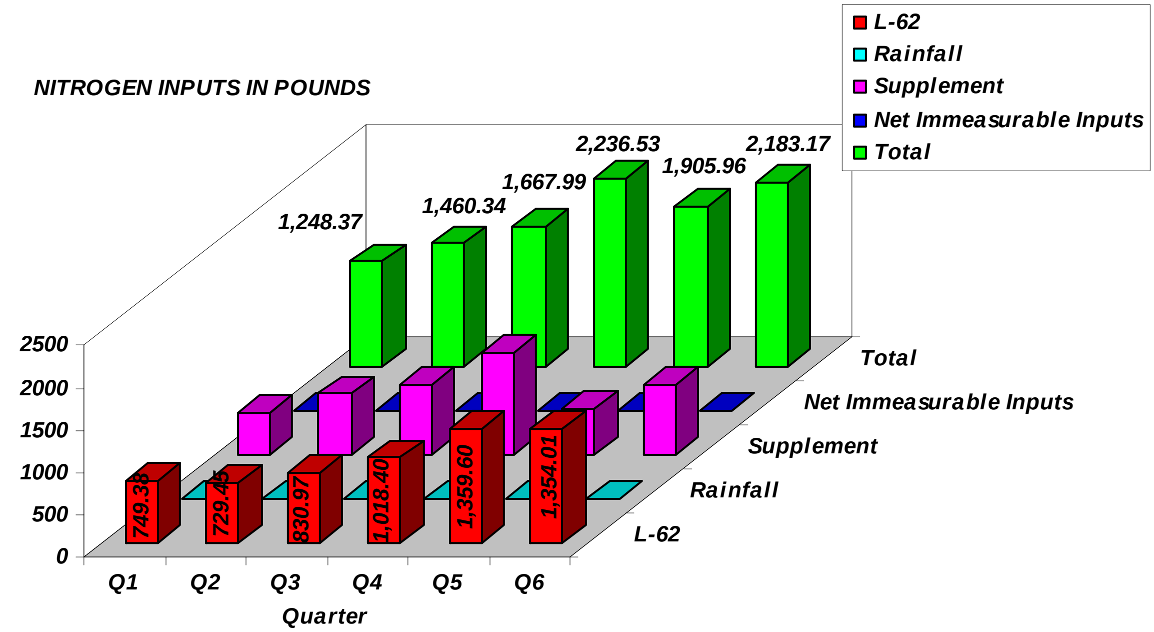


Figure 3-5: Nitrogen inputs for POR

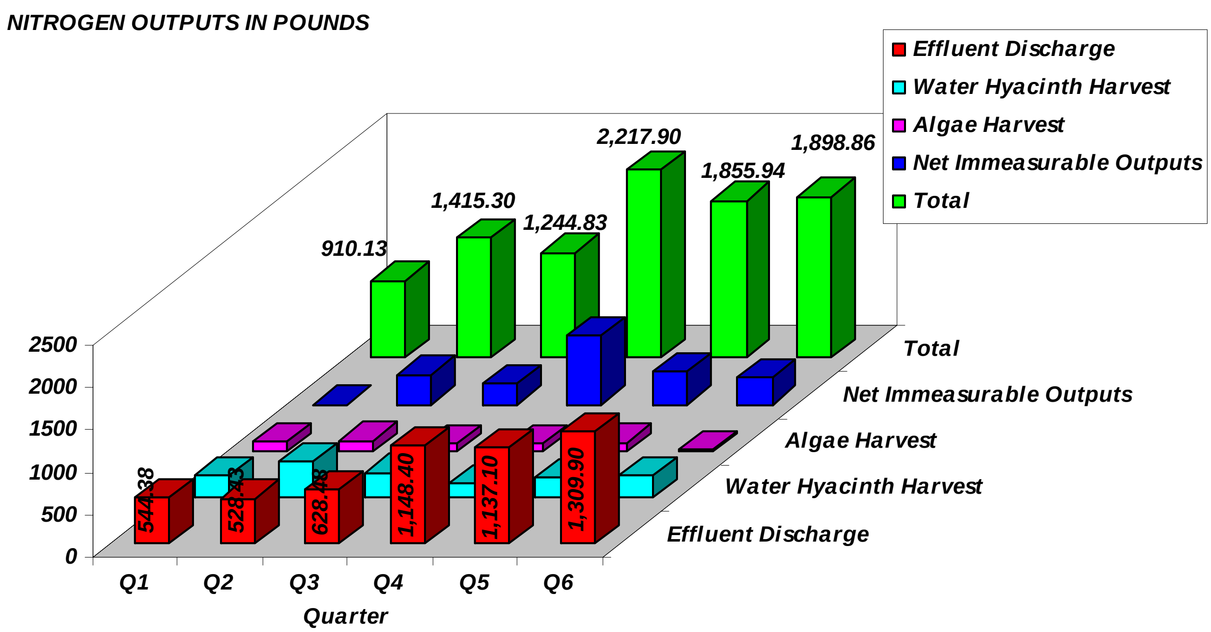


Figure 3-6: Nitrogen outputs for POR

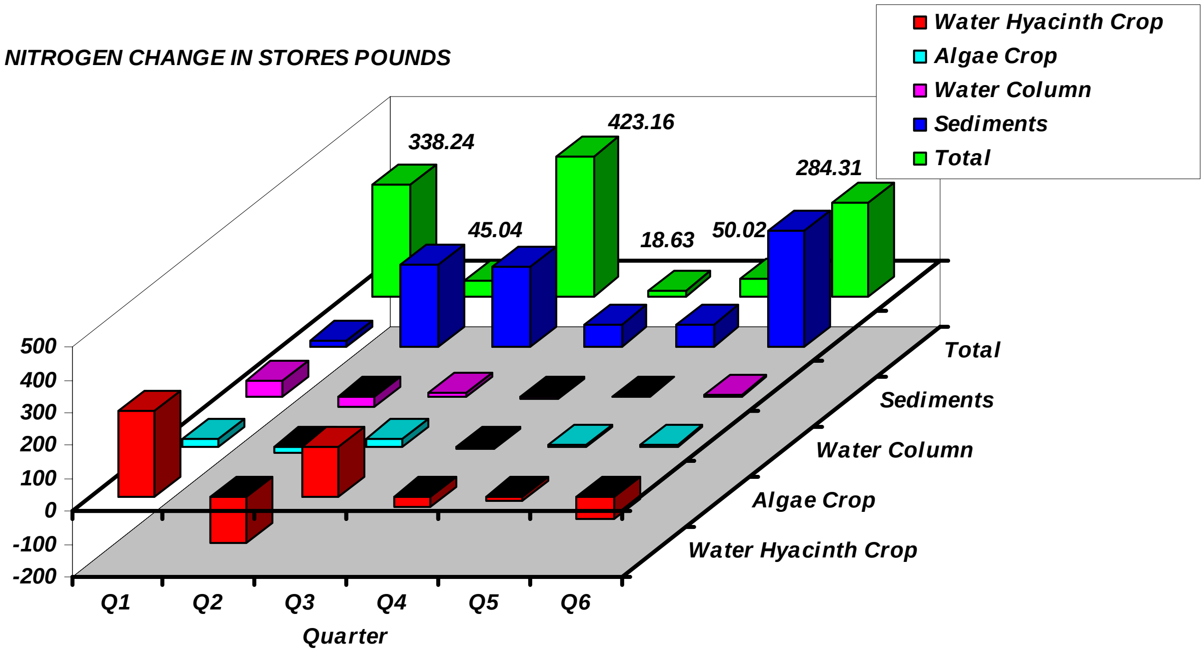


Figure 3-7: Nitrogen change in stores for POR

DISCUSSION OF WHS™ SEDIMENT DYNAMICS

With all wetland treatment systems (EMA-STA, PSTA, SAV) and intensive managed aquatic plant systems such as the (WHS™), sediment deposition is a factor in phosphorus dynamics. Sediment deposition, as noted, is not nearly as influential in nitrogen dynamics, as nitrogen within the sediments is susceptible to loss through denitrification. The deposited phosphorus typically includes chemically precipitated phosphorus as well as biologically deposited phosphorus.

The accretion rate for sediments within the WHS™ during Q1 was approximately 1.27 centimeters, or if this rate continues, approximately 5 centimeters annually. The Q1 WHS™ accretion rate is slightly higher than accretion rates for productive constructed emergent wetlands where accretion rates have been reported as high as several centimeters per year. The accretion rate for sediments within the WHS™ during Q2 was approximately 2.99 centimeters, or if this rate continued, approximately 12 centimeters annually. As noted, however, the dry weight of this deposited sediment was not much greater than Q1. The sediment was much more flocculent, and contained more fresh plant material, suggestive of extensive sloughing.

The accretion rate for sediments within the WHS™ during Q3 was approximately 2.21 centimeters, or if this rate continued, approximately 8.8 centimeters annually. The dry weight of this deposited sediment was slightly higher than Q2, indicating denser, less flocculent sediment. The phosphorus content of the Q3 sediment was also considerably lower than for Q2, hence the phosphorus accretion for this period was less. It is considered quite likely that this differential is associated with the losses during the disruptive period during Q2, and that the Q1 and Q3 phosphorus deposition rates may more closely reflect stable conditions.

During Q4 and Q5, accretion rates decreased, averaging 0.59 cm and 0.63 cm per sampling period respectively. If these rates were to continue, annual deposition would be 2.68 cm assuming Q4 rates, and 1.84 cm assuming Q5 rates. The density of deposited material during these two quarters was significantly greater than in the 3 previous quarters, at 0.13 g/cm^3 and 0.16 g/cm^3. Additionally, phosphorus content increased during both quarters relative to Q2 and Q3. It is possible that the phosphorus associated with this material is less labile than that of previous quarters, as the density is increased, likely decreasing the tendency to re-suspend into the water column under these heavier hydraulic loading rates. The accretion rates observed in Q4 and Q5 more closely resemble those associated with treatment wetlands. This trend changed in Q6 however, most likely influenced by the 2 hurricanes that struck the area between August 25 and October 9. Accretion rates increased dramatically to about 4 cm during this quarter or, if this rate were to continue, about 10.4 cm per year. Again, the bulk density was increased (0.89 g/ cm^3) and was largely composed of large pieces of sloughed water hyacinth.

As with any biological treatment system, continued sediment deposition can be expected to change nutrient dynamics, as accumulation of sediments will result in (i) decreased efficiency of the system to assimilate phosphorus loads, which may include possible regeneration of stored phosphorus, that then would then become an internal, or autochthonous load, and (ii) impacts to hydraulic flow. The net result is that all biological systems require a sediment management program.

Researchers at the University of Florida – Soil and Water Sciences Department were conducting research to develop a Sediment Management Guidebook for the City of Orlando's Easterly Wetland (OEW) Treatment System, which has experienced an accumulation of sediments in the inflow region. This buildup of organic sediments is expected to occur in most natural and constructed wetlands used for water treatment. It is expected that some sediment management practices applicable to constructed wetlands, may be applicable to the WHS™. Recent literature regarding vegetation management in constructed wetlands indicates potential water level drawdown and burning to enhance phosphorus removal in constructed wetlands (Goforth, 2005). The cost of these sediment management programs should be included in any long-term economic analysis of these treatment systems.

Scheduling of the sediment management program activities will vary, as long-term retention of phosphorus within different types of peat is variable. It is reported in the literature that peat derived from cattail vegetation is far less effective at long-term retention of phosphorus than sawgrass peat. Biological assessment of the long-term stability of organic matter (which ultimately forms peat) accreting in the WHS™ is currently not known, and was not included within the scope of this project.

As initially evaluated within the OEW, the most effective sediment management program involves the removal of accumulated sediment to restore treatment efficiency. To provide for this sediment management option, design of the WHS™ for full-scale, long-term performance include development of modules, which can be isolated and drawn down to expose the sediments, or hydraulically dredged to facilitate cost effective removal and management of the sediments.

Some indication of the magnitude of phosphorus regeneration from the WHS™ sediments is offered by looking at the phosphorus dynamic in the WHS™ component during Q1 and Q2. If the grab samples are used to develop effluent loads from the WHS™ it is estimated that 220.14 pounds of phosphorus were removed from incoming loads during Q1+Q2 through the WHS™. Hyacinth harvest, as noted, amounted to 124.65 pounds of phosphorus; increase in standing crop removed another 39.61 pounds, while sedimentation amounted to 94.58 pounds of phosphorus, therefore the total phosphorus removal would be estimated at 242.84 pounds. Of the sedimentation losses, a net of 2.51 pounds can be assigned to water column changes, therefore the net removal is estimated at 240.33 pounds. This still leaves an excess of 20.19 pounds, or the difference between calculated water losses and the summation of harvest, net growth and sedimentation, which logically would be assigned to regeneration from the sediments. Therefore the net sediment flux (positive being lost to sediments, negative being regenerated from the sediments into the water column) would be the difference in the amount of sediment lost not attributable to net loss in the water column or 94.58 lb-2.51lb = 92.07 lb, and that phosphorus regenerated into the water column. This then would be 92.07 lb- 20.19 lb, indicating a net deposition of 72.88 lb-P. Taken on an annual basis, this correlates to an areal contribution rate by the sediments of about 6.32 g/m^2-yr. Using the Walker (1997) equation for the (Dynamic Model for Stormwater Treatment Area) DMSTA model,

$$S = K_e F_w C \qquad \text{(Equation 6)}$$

Where **S** is the sediment phosphorus accretion rate of g/m^2 –yr
K_e is the effective settling velocity in m/yr, assumed to be constant
F_w is the wet period fraction, which would be 1.0 for the WHS™
C is the TP concentration as mg/l

with **C** in the WHS™ estimated as the average of influent and effluent concentrations, or about 0.345 mg/l, **K_e** is estimated at 18.3 m/yr, which is somewhat higher than the value of about 10.2 m/yr set for WCA2.

Interestingly, Qian and Richardson (1997) assessed the risk of overloading an STA system with phosphorus at 75%, when the phosphorus loading was approximately 1.30 g/m^2-yr. This is suggestive that the sediment dynamics within the WHS™ have yet to stabilize, and may well regenerate phosphorus before doing so. This is indicated by the negative values (immeasurable net inputs) of –9.05 lb, -37.84 lbs and –56.14 lbs on the right side of Equation 5 for Q2, Q3 and Q6, respectively. The net accretion rate may be expected therefore to reduce considerably over time, and return of phosphorus loads from the sediments might be expected. This additional phosphorus would show up as increased effluent levels, or as increased hyacinth production.

It must be recognized that the WHS™ -ATS™ system is an actively managed system in which the vegetative production is for the large part removed from the system. Therefore the DMSTA modeling approach may be appropriate only for making estimates of that portion of phosphorus removal attributable to sediment accretion. The larger removal by plant uptake needs to be estimated through plant production estimates, which is typically done through first order dynamics as described by Musil and Breen (1977) as applied to water hyacinths. The HYADEM model, based upon the Musil and Breen (1977) work, and as presented in Section 5, is a Monod based first order kinetics model applied to the WHS™. The net sediment loss component has been typically handled in this model by applying an incidental phosphorus loss coefficient (C_p), which is the phosphorus loss not attributable to harvested plant biomass. This coefficient can be replaced by considering a sloughing percentage applied to the specific growth rate for hyacinths, meaning a portion of the net growth is delivered to the sediments, rather than being harvested. This allows an estimate to be made regarding both harvest quantities and sediment removal quantities. This concept is examined as part of Section 5.

DISCUSSION OF ATS™ DYNAMICS

A similar evaluation can be conducted regarding nutrient balancing between harvest and calculated nutrient removals from water quality data for the ATS™/microscreen. The phosphorus removal for Q1+Q2+Q3 through the ATS™/microscreen, using the hyacinth grab samples as an estimate of influent values, was 107.52 pounds. The phosphorus in the algae harvests amounts to 44.91 pounds. The fate of the 62.61 pounds not assignable to recovered and measured harvest is not easily explained. However, when Q1 is reviewed, there is a close agreement between the water column removal of 16.90 pounds of phosphorus, and the harvested amount of 17.75 pounds of phosphorus. During Q2 however, the water column removal of 51.66 pounds of phosphorus is considerably higher than the harvest amount of 16.43 pounds. During Q3, the water column removal was 38.95 pounds of phosphorus, as compared to 10.72 pounds attributable through measured harvest, which represents a balance similar to Q2. During Q4 and Q5 the phosphorus removal through the ATS™, based upon grab samples, was 57.05 pounds. The combined harvest amount was calculated as 26.59 pounds, or an accountability of 46.6%. (Q6 is considered anomalous because of the hurricanes and is not included as part of this review). This level of accountability was also noted with the single stage ATS™ floways, as discussed in a separate report. The fate of the unaccounted for phosphorus may be associated with:

- Sampling or analytical error related to the biomass. Small grab samples are combined from the floway biomass and tested for moisture and then delivered to Midwest Laboratories for nutrient analyses. If there is wide variation within the harvested biomass in moisture content or nutrient content, this would confuse the assessed nutrient budget.

- Undetected loss of biomass. This could happen during heavy rain periods, although as the sampling protocol is flow controlled, any excessively loaded runoff would be sampled and should be included within the composite effluent sample. The collection and assessment of microscreen solids is somewhat difficult, and it is possible that some of the harvest is lost through this procedure.
- Heavy grazing and predation could account for emigration of phosphorus from the system. This could be associated with the metamorphosis of insect pupae, with the adults emigrating or from bird predation or invertebrates within the floway.
- Storage sites within the floway such as sediment deposits, or adsorption sites could retain phosphorus within the system. It would be expected however, that these sites would become saturated within a relatively short time period, and that because of the limited storage space associated with the ATS™ system, they would not offer any significant capacity.
- Deficiencies in the water sampling and analytical procedures and incorrect measurement of harvest quantity from the Duperon Flex-Rake.

Efforts to improve phosphorus accountability within the ATS™ could include:

- Review of the analytical procedures associated with the biomass, and splitting samples with two accredited laboratories.
- Conduct a field assessment of the potential impacts of grazing and predation.
- Redesign the sampling protocol for biomass
- Conduct a thorough review of the floway to determine the possibility of any significant on-site storage.

In reviewing the segregation of algal harvest, there is evidence that a significant percentage of the algae are associated with fragments that pass through the harvest rake. For example, during the entire POR, Q1 through Q6, the amount of algae removal, either by the microscreen or by-passed during harvesting activity, were measured as 60% of the 74.01 lbs of total phosphorus, while only 40% were removed by the rake. The implication is that for any proposed ATS™ system, included in the design and operational strategy shall be included means of capturing the smaller algal fragments, particularly during the harvesting sequence.

SECTION 4. BIOMASS MANAGEMENT

WATER HYACINTH SCRUBBER (WHS™)

Production and Harvesting

At the beginning of operations on January 27, 2003 at 9:30 AM—the water hyacinth standing biomass was measured at 60.20 wet tons of viable tissue, at 65% viability, or 92.74 total wet tons. The density of viable tissue was 3.07 wet lbs/ft^2 in the south WHS™ treatment unit (WHS™ -South) and 3.87 wet lbs/ft^2 in the north WHS™ treatment unit (WHS™-North). Area coverage was 32.46%. By March 17, 2003 the crop had matured to an operational mass of 140.38 wet tons viable tissue, at almost 69% viability, or 203.44 total wet tons. The crop density of viable tissue was 3.07 wet lb/ft^2 in WHS™ - South and 3.19 wet lb/ ft^2 in WHS™-North. The coverage at this time was 84.59%.

As the design standing biomass was identified as 218 wet tons within the Preliminary Engineering Report, as previously submitted, it was decided to commence harvesting on March 17, 2003. The intent was to harvest excess production such that a standing crop of 140-150 wet tons of viable tissue or about 200-215 total wet tons, is maintained, with percent viability above 70%. The desired percent biomass coverage is about 55-80 percent, which allows enough open water to permit wind movement of the crop, thereby preventing development of static areas. A series of graphs presented as Figures 4-1 through 4-5 indicate the general trends in crop development and sustenance.

As the S-154 Prototype unit is constructed with a harvest channel located on only one side of each of the WHS™ units, the desired percent coverage during the pilot study was maintained somewhat below the optimal percent coverage when harvest access is provided on two sides of the treatment unit. It is recognized that this may have a slight impact on treatment performance levels.

By the end of Q1 on May 5, 2003, the biomass had been harvested 18 times, with a removal of 168,842 wet pounds or 84 wet tons. The standing biomass on May 5 was 148.75 wet tons viable tissue, at almost 74% viability, or nearly 200 total wet tons. The crop density of viable tissue had increased to 4.37 wet lb/ft^2 in the WHS™ - South and 4.45 wet lb/ ft^2 in WHS™ - North. The percent coverage was at 64%.

By the end of Q3 on November 3, 2003, the biomass had been harvested 71 times—18 during Q1; 26 during Q2; and 27 during Q3 with a removal of 576,082 wet pounds or 287.54 wet tons, of which 84.42 wet tons were harvested during Q1; 113.04 wet tons were harvested during Q2; and 90.08 wet tons were harvested during Q3. The standing biomass on November 3, 2003 was 163.41 wet tons viable tissue, at 80.5% viability, or 200.51 total wet tons. The crop density of viable tissue was 5.53 wet lb/ft^2 in the WHS™ - South and 4.90 wet lb/ ft^2 in WHS™ - North. The percent coverage was at 58.7%.

By May 31, 2004, with only the WHS™ south in operation, the total standing crop was 115.88 wet tons viable tissue, at 83.53% viability, or 138.72 total wet tons. The crop density of viable tissue was 5.16 wet lb/ft^2 in the WHS™ - South. The percent coverage was at 83.60%.

From Quarters 4 through 6 the WHS™ south biomass was harvested 73 times—22 during Q4, and 32 during Q5, and 19 during Q6 with a total POR removal of 641,400 wet pounds or 320.70 wet tons, of which 64.17 wet tons were harvested during Q4, 127.25 wet tons were harvested during Q5 and 129.28 wet tons were harvested during Q6.

At the end of Q6, WHS™ south (which was that WHS™ still operating) had a total standing crop of 78.8 wet tons viable tissue, at 75.19% viability, or 104.80 total wet tons. The crop density of viable tissue was 5.42 wet lb/ft^2 in the WHS™ - South. The percent coverage was at 54.26%.

On December 9, 2004, process operations of the WHS™ -North system were terminated. At the time of this termination, the total standing crop was 139.87 wet tons viable tissue, at 82.35% viability, or 169.85 total wet tons. The crop density of viable tissue was 5.14 wet lb/ft^2 in the WHS™ - South and 5.24 wet lb/ ft^2 in WHS™ - North. The percent coverage was at 50.65%. Up until the end of Q4, the harvest from WHS™ - North was included in the growth rate calculations, as it was presumed that nutrients contributed from L-62 prior to December 9, 2004 were responsible for the growth of this tissue. Beginning Q5, the WHS™ -North harvest was not considered in the growth rate calculations.

Growth rate for any time period when harvesting is involved may be calculated per Equation 6.

$$Z_t = Z_0 e^{U(th1 + th2 + \ldots + thn)} - h_1 e^{U(th2 + th3 + \ldots + thn)} - \ldots - h_{n-1} e^{U(thn)} - h_n \qquad \text{(Equation 6)}$$

Where Z_t is the standing crop after the time period $S(t_{h1},t_{hn})$, **h** is the harvest amount, **t** is the time period in days between harvests, and **U** is specific growth rate in 1/day. For Q1 the average growth rate was calculated at 0.0127/day; for Q2 it dropped considerably to 0.0036/day; it increased during Q3 to 0.0079/day, averaging 0.0115/day for the combined Q1 + Q2 +Q3. Until the disruptive event in early July, the Q2 growth rate is calculated at about 0.0087/day. Projected growth rate for the system was estimated at about 0.017/day, but this was calculated assuming no tissue sloughing and no phosphorus accretion to the sediments (C_p=0). The lower growth rates prior to the disruptive event are likely attributable to higher crop densities. Recovery of growth during Q3 indicates a response to efforts to reduce densities.

For Q4 the average growth rate was calculated at 0.0053/day; for Q5 it increased to 0.0118/day; for Q6 the calculated rate was 0.0063/day, with an average 0.0078/day for the combined Q4-Q6, and 0.0093/day for the entire POR.

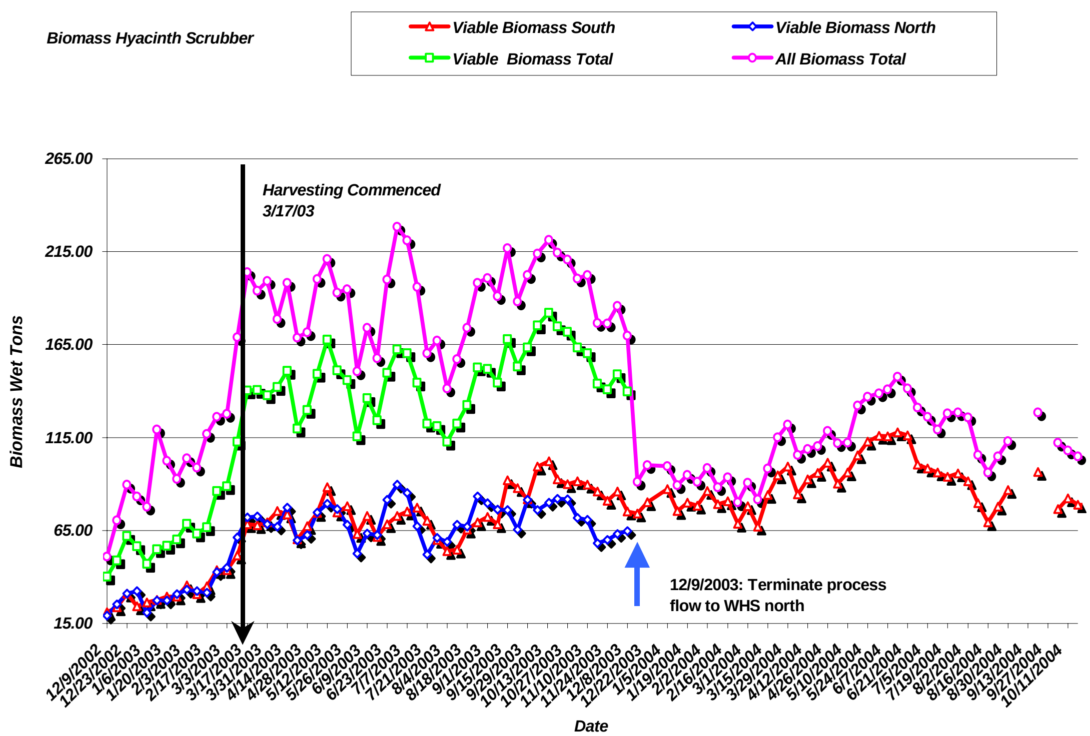


Figure 4-1: Water hyacinth standing crop development for the period January 27, 2003 through October 18, 2004

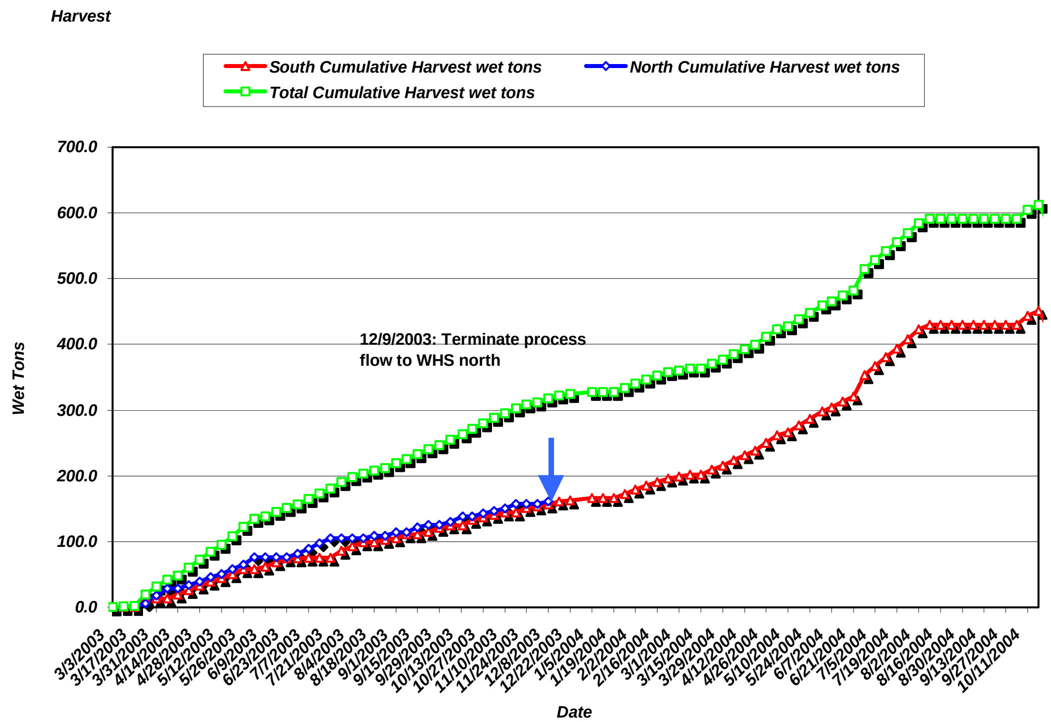


Figure 4-2: Water hyacinth biomass harvest for the period January 27, 2003 through October 18, 2004

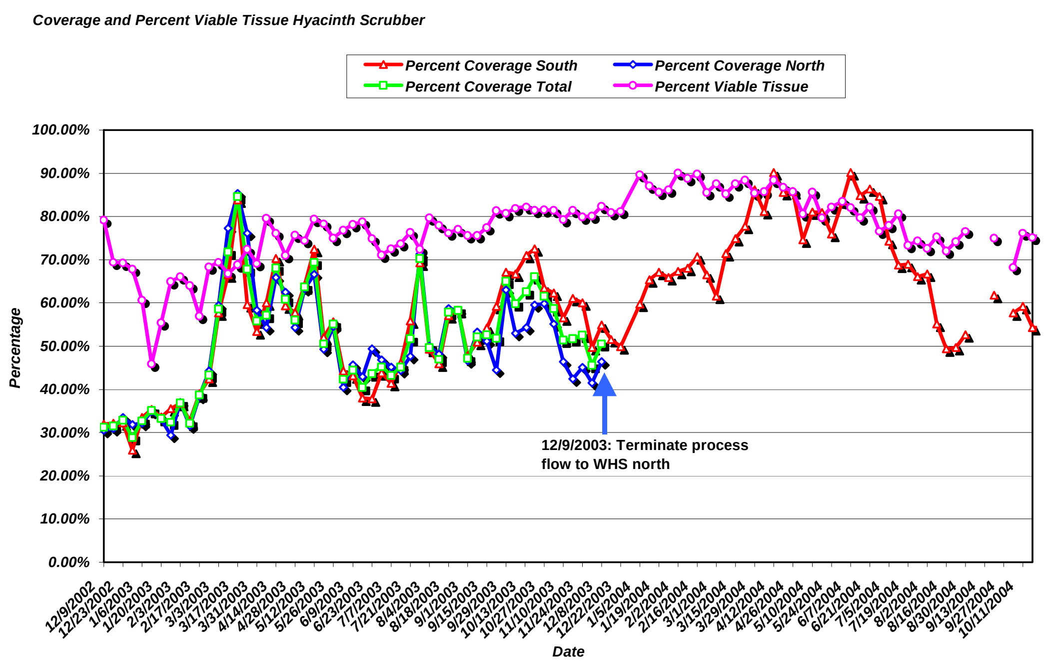


Figure 4-3: Water hyacinth percent viability and coverage for the period January 27, 2003 through Ocotober 18, 2004

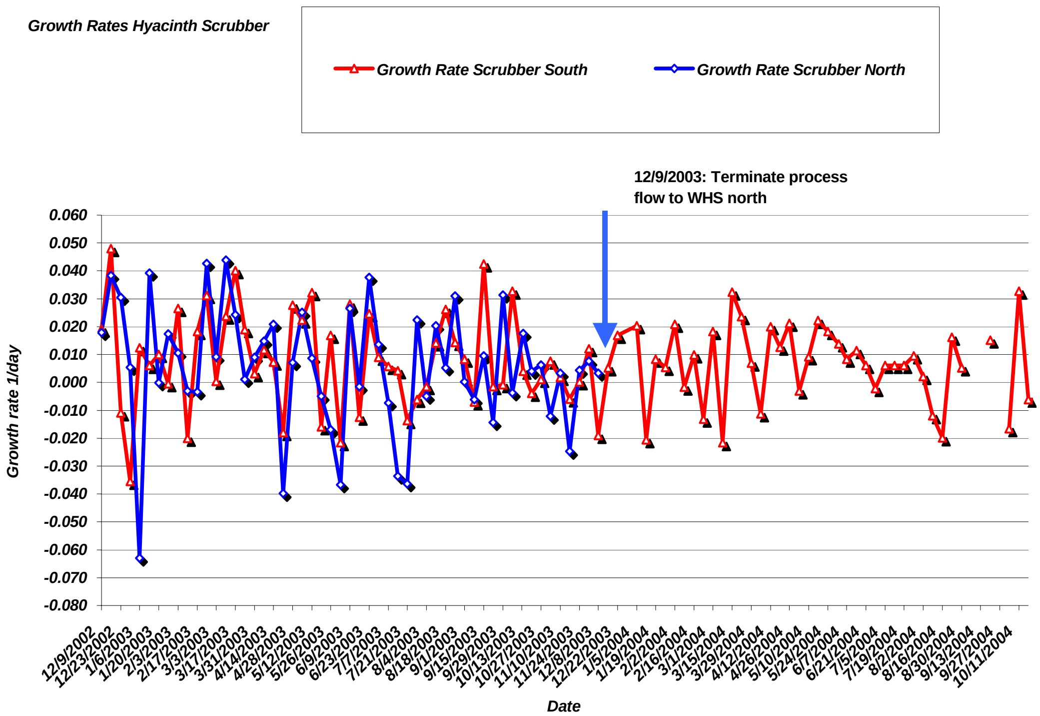
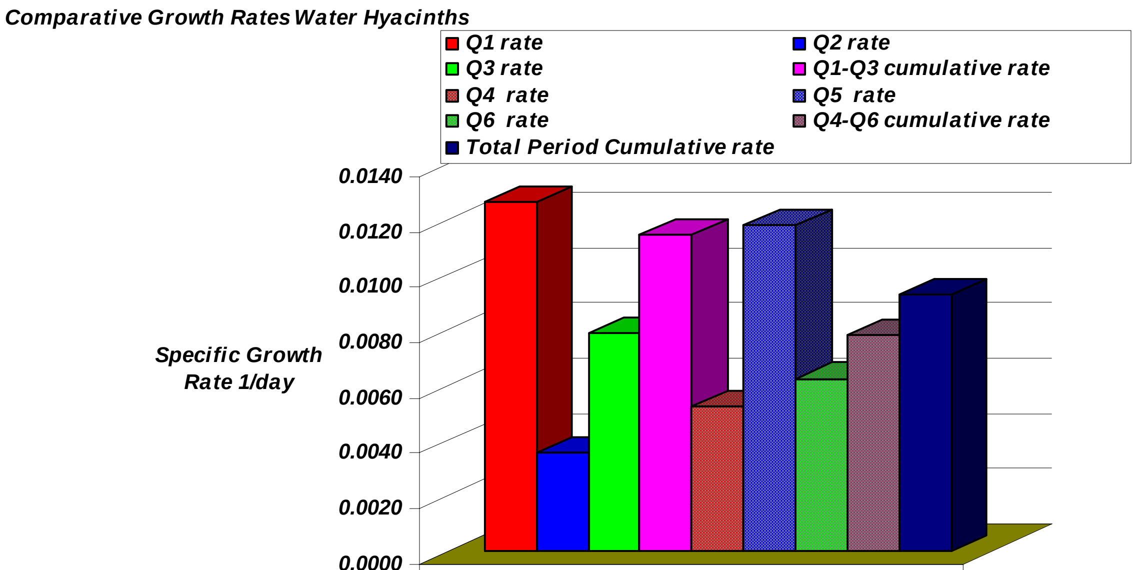


Figure 4-4: Water hyacinth growth rates for the period January 27, 2003 through October 18, 2004



	Time Period
Q1 rate	0.0127
Q2 rate	0.0036
Q3 rate	0.0079
Q1-Q3 cumulative rate	0.0115
Q4 rate	0.0053
Q5 rate	0.0118
Q6 rate	0.0063
Q4-Q6 cumulative rate	0.0078
Total Period Cumulative rate	0.0093

Figure 4-5: Water hyacinth average growth rates by quarter for the period January 27, 2003 through October 18, 2004

During the disruptive event period from July 7, 2003 until August 4, 2003, the viable tissue percentage increased from 72.49% of 221.21 wet tons, or 60.85 wet tons of non-viable tissue, to 79.71% of 141.48 wet tons, or 28.71 wet tons of non-viable tissue. During this period 33.33 wet tons was harvested, and the average viable tissue percentage was 74.96, therefore about 8.35 wet tons of non-viable tissue was harvested. The implication is that during this time 23.79 wet tons of additional non-viable tissue was delivered to the sediments, adding to the normal rate of sloughing. Assuming this shed tissue was 0.49% P, 2.22% N and 5% solids, it is estimated that this sloughing contributed 11.65 pounds of phosphorus and 52.81 pounds of nitrogen to the sediment load for the quarter, or 17.24% and 21.60% of the total sediment load, respectively.

The same analysis for the period before the disruptive period, from May 5, 2003 to July 7, 2003, shows the viable tissue percentage changed from 74.52% of 200.23 wet tons, or 51.01 wet tons of non-viable tissue, to 72.49% of 221.21 wet tons, or 60.85 wet tons of non-viable tissue. During this period 79.71 wet tons was harvested, and the average viable tissue percentage was 76.34%, therefore about 18.86 wet tons of non-viable tissue was harvested. The implication is that during this period there was no additional sloughing beyond the normal rate, but rather an accumulation within the standing crop. During Q3 the viable tissue percentage was rather stable, increasing from 79.71% to 81.50%, indicating improved plant health. Viable tissue percentage remained stable throughout Q4, Q5 and Q6.

As noted in Figure 4-6, crop density increased through the end of March to the end of Q1, and continued to increase until July 7, 2003. After July 7, the density declined significantly, likely because of tissue sloughing. During the week of July 21, efforts were made to manually spread the crop to reduce density to a more desirable level of about 3.50-5.00 wet pounds/ft^2. The recorded increase is influenced by the biomass management program as well as seasonal temperature and solar radiation impacts. In general the plants tend to grow vertically more in the warmer weather, while lateral growth is often seen to be more predominant in the cooler months. Percent coverage is noted to vary considerably with wind speed. The stronger the wind, the more tightly packed are the plants, which increases density while reducing percent coverage.

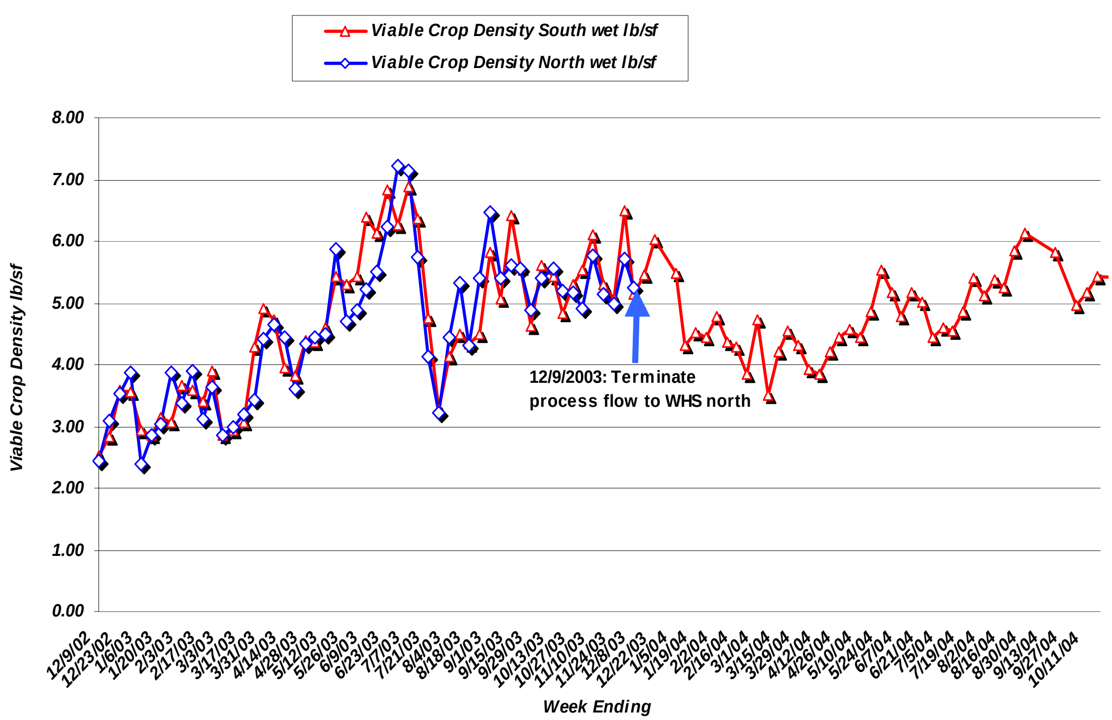


Figure 4-6: Water hyacinth wet densities for the period December 9, 2003 through October 18, 2004

During Q3, and continuing into Q4 and Q5, the crop density stabilized within the range of 3.5-5.0 wet pounds/ft^2, which contributed to improved crop health and growth during this period. Crop density ranged from 4.4-6.1 pounds/ft^2 during Q6. Average crop density for Q4-Q6 was about 5.2 pounds/ft^2, with a fair amount of new growth on each weekly observation.

Standing crop sampling is done per the approved Monitoring Plan using a PVC grid of a set area (4 square feet), and then random sampling in each of four equally sized sections within the WHS™ treatment units. The plants are weighed after a period of draining—i.e. when the weight ceases to change. As noted, these plants are typically about 5% solids, or 95% water by weight. To assess the level of reliability of sampling methodology, testing was performed in conjunction with the Quality Assurance and Control Plan. A 500 square foot PVC grid was placed in each treatment unit. Plant density was determined within the grid area using the 4 square foot sampler. After sampling, the entire biomass within the grid was removed by hand, weighed and the findings compared to the biomass determined through sampling. The net result showed the biomass determined by the sampling method 19.2% higher than the actual biomass. The difference was determined to be related to (i) loss of necrotic tissue during biomass removal, as necrotic tissue is captured on the sampling grid and (ii) inconsistent removal of free water during the drainage period.

The observed variability in crop sampling results is related to some extent to fluctuations in crop density during varying wind conditions. This variability impairs the accuracy of the sampling method. However, these tend to level out when reviewed on a long-term basis. There are no cost-effective alternatives for measuring standing crop with a greater degree of accuracy. However, for full-scale operations, the biomass monitoring program, in conjunction with the supplementary biological monitoring programs discussed later in this section have proven to provide the system operator sufficient information to effectively manage the WHS™ system.

Crop quality and morphology changed noticeably over Q1 in response to nutrient availability, grazing pressure, climate changes, and harvesting influences. Prior to start-up initiation, flow to the WHS™ units was intermittent. Consequently, during this early period the crop developed in a phosphorus deficient environment. Nitrogen was maintained at high levels during this time through supplementation. The paucity of phosphorus was indicated by water quality results, with total phosphorus levels dropping to as low as 18 ppb during the pre-start-up period. This resulted in an extension of the root mass as the plants sought to increase root surface area to capture available phosphorus. Once continuous flow was initiated, the ratio of shoot length to root length (shoot:root) increased. At the same time, the percent viable tissue began to drop as the plants began to abandon the longer roots.

While the plants were stocked initially as "weevil-free", infestation was noticeable within one week of stocking. Weevil numbers remained low until late March, when the extent of weevil infestation increased, presumably from a "swarming" of adult weevils. (Adult weevils develop extensive flying muscles during certain times of the year, and as a result they have become ubiquitous in Florida). After the commencement of harvesting, a trend of reduction of weevil impacts became evident. During Q1 the peak weevil population was noted during mid April at 4.63 weevils (adults + larvae) per plant. By May the number was reduced to 1.8 weevils per plant. Weevils remained under control during the POR, likely because of the periodic application of nematodes.

Harvesting of hyacinth biomass has always been viewed as a potentially effective weevil management strategy, because of the continual removal of the insects, and the subsequent interruption of the life cycle. As long as swarming is not occurring, harvesting serves as an effective weevil control strategy.

In addition to harvesting, predatory nematodes were applied during Q1, with applications continuing throughout the remaining POR. Nematodes used for insect control are multicellular parasites, and parasites and predators are not regulated by the US EPA. The applied nematodes contributed to enhanced control of the weevil larvae. Other grazers, such as spider mites, and the hyacinth moth were seen on occasions early in the operational period, but not in high concentrations. By May, 2003 these elements had been eliminated. Pathogens were absent during all six quarters, and plant health remained high. However, during Q2, increased plant density resulted in the creation of a extensive canopy above the plant mass near the water surface, and served to reduce light availability in this substructure, which may have impacted productivity and lateral growth. The disruptive event of July appears to have also impacted crop production during Q2.

Near the end of Q2, floating barriers were installed in the two WHS™ treatment cells to reduce cell size, and relieve the pressures associated with extensive crowding. This resulted in improved production during Q3. Supplementation of essential elements continued through Q5, with some adjustments (increases) made to copper and nitrogen supplementation. A program of spraying a urea solution onto the crop was initiated during Q2. This supplementation protocol was continued through Q3. Spraying of urea was discontinued by the end of Q3 because of a concern related to nitrogen contamination within water samples.

Plant quality and morphology was monitored and recorded monthly. Through Q4, as the nutrient levels within the L-62 feedwater decreased, there was a notable decline in shoot:root ratio, as expected. This ratio dropped to a low of 0.49:1 by March, 2004, before starting an increase in April and May, as a result of increasing nutrient levels. By May, 2004 the shoot:root ration had increased to 1.14:1. These observations are presented within Table 4-1. This analysis was discontinued during Q6 but increased nutrient content in the feedwater would indicate a continuation of this trend.

Table 4-1: Water hyacinth crop health and morphology for the period January 27, 2003 through May 28, 2004.

	12/6/03	**1/16/03**	**2/16/03**	**3/17/03**	**4/16/03**
Average Root Length (inches)	23.0	19.6	16.6	9.0	16.3
Average Shoot Length (inches)	12.8	10.9	8.2	13.9	16.3
Shoot:Root ratio	0.56:1	0.55:1	0.49:1	1.54:1	1.00:1
Chlorosis	slight	rare	none	slight	none
Streaking	rare	none	none	slight	none
Weevil adults/plant	0.31	0.65	0.50	0.23	1.75
Weevil larvae/plant	0.50	0.47	0.56	1.00	2.88
Moth larvae/plant	0.13	0.06	0.90	0	0.06
Hyacinth mites infected leaves/plant	1	2	0	0	0
Spider mite infected area sq. ft.	17	90	0	0	0

Table 4-1: Continued

	5/16/03	6/16/03	7/18/03	8/19/03	9/20/03	10/22/03
Average Root Length (inches)	10.8	11.0	10.8	13.2	13.6	13.3
Average Shoot Length (inches)	19.7	21.3	25.1	28.2	29.0	24.8
Shoot: Root ratio	1.79:1	1.94:1	2.32:1	2.14:1	2.10:1	1.86:1
Chlorosis	None	None	None	None	None	None
Streaking	None	None	None	None	None	None
Weevil adults/plant	0.90	2.30	1.29	0.75	1.67	1.92
Weevil larvae/plant	0.90	0.50	0.43	0.67	0.58	0.83
Moth larvae/plant	0	0	0	0	0	0
Hyacinth mites infected leaves/plant	0	Few	Few	1	2	2
Spider mite infected area sq. ft.	0	0	0	0	0	0

	11/19/03	12/22/03	1/23/04	2/23/04	3/31/034	4/30/04	5/28/04
Average Root Length (inches)	14.4	9.4	10.4	12.3	20.8	27.5	20.3
Average Shoot Length (inches)	22.6	21.8	15.7	9.3	8.6	16.2	23.3
Shoot: Root ratio	1.57:1	2.32:1	1.51:1	0.76:1	0.41:1	0.59:1	1.14:1
Chlorosis	None	None	None	None	None	None	None
Streaking	None	None	None	None	None	None	None
Weevil adults/plant	2.50	0.80	0.75	0	0	0	1.00
Weevil larvae/plant	1.00	0.50	0.50	0.20	0.20	0.60	0.50
Moth larvae/plant	0	0	0	0	0	0	0
Hyacinth mites infected leaves/plant	0	1.00	0.20	0	0	0	0
Spider mite infected area sq. ft.	0	0	0	0	0	0	0

The most notable changes during Q2 were the increase in the shoot:root ratio to 2.32 by August, and the increase in weevil adults, but a decrease in larvae. The higher ratio is associated with a higher crop density. The adult weevil numbers indicate an increase in immigration, which is typical for the summer months. However, the lower larvae numbers suggest the nematode program has been effective in managing larvae impacts. During Q3, in response to reduced densities, the shoot:root ratio dropped to 1.86 by October. The weevil populations were essentially unchanged from Q2, with larvae numbers remaining manageable.

Harvesting of the hyacinth biomass was accomplished using techniques and equipment developed and patented by HydroMentia. The general harvesting scheme includes the following steps:

1. The weir within the harvest flume is closed, and the flume is filled using the by-pass line. The harvest flume runs the length of the two WHS^{TM} units and is serviced by a parallel shell road on either side.
2. During filling of the harvest flume, the grapple unit, as illustrated in Section 1 moves along the service road to capture plants and move them into the harvest flume.
3. The flume can hold about 60 grapples, which amounts to about 10,000 to 15,000 pounds.

Once the flume is full, the weir gate is elevated, and the Aquamarine Conveyor is activated. The hyacinth mass is moved by the water flow to the conveyor, which moves the plants vertically to the intake of the hyacinth chopper.

4. The hyacinth chopper reduces the harvest volume, with the resulting product being a homogenous material with a density of about 25-35 lb/ft^3.
5. The chopped product is loaded into a truck and transported to McArthur Farms as a feed ingredient. Any excess material is blended with straw and composted on site.

The harvest procedure is consistent with that employed within a large-scale WHS™ treatment facility, with the exception of the flume transport system. Within full-scale systems, if a flume were to be used, it would support a continuous effluent flow of 1.5 – 2.0 fps, with a minimum water depth of 1.5 ft. In addition, the flume would not be tapered at the conveyor intake. With these conditions, the use of a blocking weir would not be required, and plant feed to the conveyor would be done during the grapple phase of the harvest. For very large systems, the hyacinth chopper would be mobilized, and the grapple would feed it directly. Chopped plants would be loaded into a transport wagon, which would deliver them to a central processing area. Because of the size of the prototype in terms of flow availability, and the need to reduce the pilot systems costs, these efficiencies within the typical harvest flume design were modified for the S-154 Prototype WHS™ Unit.

Following is a performance summary of the primary WHS™ biomass management facilities for the S-154 Prototype:

Grapple System: HydroMentia designed unit, Tractor PTO drive. With a skilled operator this unit was designed to deliver one grapple every 25 seconds. The weight of biomass collected within the grapple is dependent upon crop density. The grapple area is approximately 70 square feet. At the typical density of 5-lbs/sf density, the average grapple weight is 350 pounds. This correlates to an hourly harvest rate of about 25 wet tons/hour. Field performance of the grapple for Q1 through Q3 has been in the range of 15 – 25 wet tons/hour.

Aquamarine Conveyor: The stainless steel biomass conveying system is manufactured by Aquamarine Industries of Waukesha, Wisconsin. Aquamarine is a leading manufacturer of aquatic plant harvesters. The S-154 unit is hydraulic powered, with variable belt speed of zero to about 3 fps. The unit is rated with a load transfer capacity of 5,000 lbs/min (150 tons/hour).

Hyacinth Chopper: HydroMentia designed unit. Electric powered (75 HP), chain drives, and includes a hopper, a header unit, a forage chopper unit, and a screw product delivery conveyor. The chopper is trailer mounted, and can be mobilized. After field adjustment, the unit consistently operated at delivery rates of approximately 40 wet tons/hour.

Upon initiation of hyacinth harvesting, an attempt was made to weigh the harvest with a certified scale attached to the grapple device. The resulting weights differed considerably from the weight of the chopped product weighed on a State certified platform scale and a State certified truck scale (located at McArthur Farms). Readings for the same chopped harvest product on the platform scale and the truck scale matched closely. Because of the variance, which most likely relates to the amount of free water within the whole plants, the grapple scale was not used. All harvest weights included within this report were obtained from State certified scales - either from the McArthur Farms certified truck scale or the on-site platform scale. The material weighed is a well-drained chopped hyacinth product. Of the total harvest, all but a small percentage was delivered to McArthur Farms, where it was used as a greenchop feed ingredient.

Nutrient Supplementation

A nutrient supplementation program for WHS™ was developed and implemented to ensure the hyacinth biomass is provided sufficient amounts of essential elements, thereby isolating phosphorus as the only nutrient allowed to become limiting. The benefits of a mineral supplementation program was recognized and discussed within the Preliminary Engineering Report. Within the report it was noted that nitrogen supplementation would increase the N:P ratio, and thereby ensure nitrogen does not become growth limiting while optimizing phosphorus removal. It was projected that about 50 lbs/day of KNO_3 , equivalent to 6.6 lbs/day nitrogen, would be required for the WHS™ units. By the end of Q1, nitrogen was being supplemented to the WHS™ both as KNO_3 (13.2% nitrogen) and as urea (45% nitrogen) at the rate of 5.59 lbs/day. Of this amount, 3.60 lbs-N/day were provided by urea. The KNO_3 provided 1.99 lbs-N/day, and provided the additional benefit of supplementing potassium at a rate of about 5.8 pounds/day. During Q2 and Q3, up to six pounds additional urea was added each week through the irrigation system.

In addition to nitrogen and potassium, other elements supplemented to the WHS™ units were iron as ferrous sulfate; magnesium and calcium carbonate as dolomite; and boron as “Etibor”. During Q2, small amounts of copper were added because of the low levels within L-62.

While a review of water quality conditions indicated sufficiency of magnesium, potassium, calcium, and iron, past experiences with WHS™ treatment units have shown that in highly productive scenarios the plants will uptake these elements—particularly iron—at high rates, and that deficiencies can develop within plug flow systems. Iron addition, for example was included as part of the program when chlorosis (leaf yellowing) became evident in early March. HydroMentia has previously observed magnesium deficiency at other large-scale WHS™ treatment facilities. Dolomite is a cost effective source of magnesium.

During Q1 the WHS™ supplementation program included:

- Potassium nitrate added through the volumetric feeder at the rate of 15 pounds daily.
- Urea added through the volumetric feeder at the rate of 8 pounds daily.
- Boron added as the product “Etibor” at the rate of 4 grams daily. This has been typically added by hand.
- Dolomite added by hand at the rate of 12.5 pounds daily.
- Ferrous sulfate added by hand at the rate of 5 pounds daily.

During Q2 and Q3, some adjustments were made to the program:

- Potassium nitrate continued to be added through the volumetric feeder at the rate of 15 pounds daily.
- Urea continued to be added through the volumetric feeder at the rate of 8 pounds daily, and at the rate of 6 to 9 pounds per week through irrigation.
- Boron continued to be added as the product “Etibor” at the rate of 4 grams daily. This has been typically added by hand.
- Dolomite added by hand at the average rate of 9 pounds daily until July 7, 2003 when it was increased to 18 pounds daily.
- Ferrous sulfate added by hand at a reduce rate of 3 pounds daily, until July 7, 2003, when it was increased to 7 pounds daily.
- Copper sulfate was included as an additive to the WHS™ a the rate of 0.041 pounds daily after mid June.

During Q4 and Q5, further adjustments were made to the program:

- Because of evidence of some potential ammonia contamination of water samples, the volumetric feeder was removed from service and from the influent trailer, which also housed the automatic sampler. Spray irrigation of urea was also discontinued.
- Effluent recycling on the ATS™ was discontinued, as was the addition of muriatic acid, which was required for pH adjustment during the recycle period.
- Nitrogen was added by hand at a rate of about 16 lb/day for the entire system, until 1/5/04, at which time it was reduced because of the lower incoming phosphorus concentrations, and to ensure effluent nitrogen concentrations were lower than influent concentrations (prior to supplementation.)
- Addition of iron, copper, boron, and manganese continued as deemed necessary.
- After 1/5/04, nitrogen addition was limited to the WHS™ system, and at a low rate-about 1 lb/day, to accommodate the low nutrient concentrations within the effluent.
- On 3/14/04 nitrogen supplementation was increased to 5 lb/day, with a small amount to the ATS™, in response to increase influent nutrient concentrations. By the end of Q5, the supplementation rate for nitrogen was increased to about 7 lb/day.
- During the week of 7/19/04, nitrogen supplementation was again decreased to slightly less than 5 lb/day. Nitrogen supplementation was increased to about 6 lbs/day following the hurricanes in order to compensate for increased phosphorus concentration in the influent water.

Tissue Quality

Water hyacinth tissue samples were collected weekly, dried, and held to be included in a monthly composite sample. Heavy metals were analyzed on a quarterly basis through Q4. This composite sample was delivered to Midwest Laboratories for analysis. The results are noted within Table 4-2.

The high levels of iron are typical of water hyacinth, and suggestive of either an elevated physiological requirement, or ability for either luxury storage, or external collection along the root surface. A similar, but not as exaggerated situation is associated with manganese, boron and zinc. As noted within the table, the early start-up biomass (12/16/03) is low in phosphorus, for reasons associated with intermittent flow as previously mentioned. Protein content is also low in the start-up plants, with high ash content in the 1/17/03 sample. This may be related to the low viable tissue value noted for this period. The recovery of plant health is noted during Q1, with an increase in phosphorus and protein content, and a reduction of ash. The biomass does not show any mineral deficiencies, based upon these analyses, and general field observations. This trend is sustained in Q2, although somewhat lower protein and higher fiber values are noted in the July data. This is attributable to increased crop density, and the development of longer, fibrous petioles. The phosphorus content and protein within the plants is consistent through Q3, ranging from 0.45 to 0.51% on a dry weight basis for phosphorus and 14.1% to 16.3% for protein. By December, 2003 and through much of Q5, there is a notable decline in phosphorus content, dropping from 0.48% in November to a low of 0.24% in February, 2004, before recovering to 0.39% in May 2004. This trend corresponds to a significant decrease in phosphorus influent concentration during this period. Protein content was also somewhat variable during Q4 and Q5, falling to a low of 13.6% in April, 2004 before recovering to 14.2% in May, 2004.

Of the heavy metals, only arsenic and chromium were detected during Q2, while arsenic, chromium and lead were detected during Q1. Mercury, cadmium, and selenium were undetected in both samples. Mercury was detected during Q3 as 0.16 ppm. Cadmium, chromium, arsenic and selenium were not detected during Q3. During Q4, chromium was detected at 1.2 ppm and mercury at 0.06 ppm, while cadmium, arsenic, lead and selenium were not detected. Arsenic levels of 0.64 ppm and 0.76 ppm for Q1 and Q2 respectively, are considerably lower than the EPA limit of 75 ppm for sludges to be land applied (Rechigl,1995). Similarly, chromium levels of 1.1, 2.4 and 1.2 ppm for Q1,Q2 and Q4 respectively are lower than the EPA sludge limit of 3,000 ppm. The limit for lead is 840 ppm, while the Q1 value was 0.60 ppm. The suggested maximum tolerable dietary level for cattle for total arsenic is 150 ppm, for lead is 30 ppm and for mercury 2 ppm (NRC,1980). The relatively minor amounts found in the hyacinth material are considered safe for use as a livestock feed.

Table 4-2: Water hyacinth tissue quality for January 27, 2003 through October 18, 2004.

	Start-up 12/20/02	Start-up 1/17/03	Feb	March	April	May	June	July	Sufficiency Level Guidelines
Phosphorus (% dw)	0.16	0.28	0.29	0.36	0.45	0.45	0.45	0.49	0.25-0.40
Nitrogen (% dw)	-	2.40	2.46	2.45	2.40	2.61	2.35	2.22	-
Sodium (% dw)	0.73	0.33	0.56	0.70	0.49	0.75	0.86	0.80	-
Calcium (% dw)	1.64	1.25	1.36	2.01	1.86	2.12	2.20	2.13	1.9-2.5
Magnesium (% dw)	1.11	0.55	0.60	0.74	0.60	0.73	0.76	0.65	0.35-050
Potassium (% dw)	5.13	2.62	2.98	3.62	2.88	2.49	3.53	2.87	2.0-3.0
Iron (mg/kg)	3,468	2,441	1,352	2,348	3,842	4,569	3,254	4,016	50-150
Sulfur (% dw)	0.71	0.35	0.37	0.46	0.32	0.42	0.37	0.33	0.25-0.50
Zinc (mg/kg)	43	42	42	90	33	61	37	24	20-40
Copper (mg/kg)	7	7	3	11	5.4	15	4	8	5-15
Boron (mg/kg)	-	--	-	-	77.8	-	-	38.5	10-30
Manganese (mg/kg)	191	186	116	229	401	555	543	796	30-100
Cadmium (mg/kg)	-	-	-	-	BDL	-	-	BDL	-
Chromium (mg/kg)	-	-	-	-	1.1	-	-	2.4	-
Arsenic (mg/kg)	-	-	-	-	0.67	-	-	0.74	-
Lead (mg/kg)	-	-	-	-	0.60	-	-	BDL	-
Selenium (mg/kg)	-	-	-	-	BDL	-	-	BDL	-
Mercury (mg/kg)	-	-	-	-	BDL	-	-	BDL	-
Crude Protein (% w)	13.8	12.10	15.4	15.3	15.0	16.3	14.7	13.9	
Crude Fat (% dw)	2.04	2.33	-	-	-	-	-	-	-
Acid Detergent Fiber (ADF) (% dw)	29.1	47.10	30.3	31.2	36.4	32.8	33.3	35.2	-
Ash (% dw)	14.8	34.10	15.0	15.6	21.4	18.0	15.3	11.1	-
Total Digestible Nutrients (TDN) (% dw)	54.4	42.7	68.0	67.0	61.0	65.2	64.6	62.4	-
Net Energy Lactation (Mcal/lb)	0.72	0.49	0.70	0.69	0.63	0.67	0.66	0.64	-
Net Energy Maintenance (Mcal/lb)	0.53	0.36	0.69	0.67	0.60	0.65	0.65	0.62	-
Net Energy Gain (Mcal/lb)	0.30	0.17	0.42	0.40	0.32	0.38	0.37	0.34	-
Digestible Energy (Mcal/lb)	1.09	-	-	-	-	-	-	-	-
Metabolizable Energy (Mcal/lb)	1.01	-	-	-	-	-	-	-	-

Table 4-2: Continued

	August	September	October	November	December	Sufficiency Level Guidelines
Phosphorus (% dw)	0.51	0.48	0.46	0.48	0.39	0.25-0.40
Nitrogen (% dw)	2.50	2.26	2.13	2.43	2.62	-
Sodium (% dw)	0.85	0.42	0.37	0.31	0.35	-
Calcium (% dw)	2.20	2.03	1.83	2.02	1.81	1.9-2.5
Magnesium (% dw)	0.75	0.56	0.57	0.62	0.67	0.35-050
Potassium (% dw)	3.72	3.85	4.57	4.71	3.79	2.0-3.0
Iron (mg/kg)	2,365	2,869	1,610	1,062	946	50-150
Sulfur (% dw)	0.48	0.26	0.26	0.28	0.35	0.25-0.50
Zinc (mg/kg)	48	34	37	41	77	20-40
Copper (mg/kg)	11	11	12.4	11	11	5-15
Boron (mg/kg)	-	-	31.4	-	-	10-30
Manganese (mg/kg)	1,174	1.205	987	677	500	30-100
Cadmium (mg/kg)	-	-	BDL	-	-	-
Chromium (mg/kg)	-	-	BDL	-	-	-
Arsenic (mg/kg)	-	-	BDL	-	-	-
Lead (mg/kg)	-	-	BDL	-	-	-
Selenium (mg/kg)	-	-	BDL	-	-	-
Mercury (mg/kg)	-	-	0.16	-	-	-
Crude Protein (% w)	15.6	14.1	15.2	15.8	16.4	
Crude Fat (% dw)	-	-	-	-	-	-
Acid Detergent Fiber (ADF) (% dw)	35.1	38,5	33.5	33.0	36.7	-
Ash (% dw)	14.8	15.3	15.8	16.7	15.3	-
Total Digestible Nutrients (TDN) (% dw)	52.5	58.7	64.4	64.9	60.7	-
Net Energy Lactation (Mcal/lb)	0.64	0.60	0.66	0.67	0.62	-
Net Energy Maintenance (Mcal/lb)	0.52	0.57	0.64	0.67	0.60	-
Net Energy Gain (Mcal/lb)	0.34	0.34	0.37	0.38	0.36	-
Digestible Energy (Mcal/lb)	-	-	-	-	-	-
Metabolizable Energy (Mcal/lb)	-	-	-	-	-	-

Table 4-2: Continued

	January 2004	February 2004	March 2004	April 2004	May 2004	Sufficiency Level Guidelines
Phosphorus (% dw)	0.35	0.24	0.30	0.39	0.39	0.25-0.40
Nitrogen (% dw)	2.76*	2.56	1.82	2.13*	2.23	-
Sodium (% dw)	0.54	0.68	0.58	0.48	0.42	-
Calcium (% dw)	2.01	1.81	1.62	-	1.70	1.9-2.5
Magnesium (% dw)	0.69	0.83	0.80	0.78	0.64	0.35-050
Potassium (% dw)	4.05	4.26	4.03	3.63	4.24	2.0-3.0
Iron (mg/kg)	904	2,358	2,463	5,153	8,607	50-150
Sulfur (% dw)	0.33	0.38	0.40	0.46	0.47	0.25-0.50
Zinc (mg/kg)	62	72	45	45	45	20-40
Copper (mg/kg)	10	9	10	12	20	5-15
Boron (mg/kg)	24.9	-	-	-		10-30
Manganese (mg/kg)	599	642	607	544	650	30-100
Cadmium (mg/kg)	BDL	-	-	-		-
Chromium (mg/kg)	1.2	-	-	-		-
Arsenic (mg/kg)	BDL	-	-	-		-
Lead (mg/kg)	BDL	-	-	-		-
Selenium (mg/kg)	BDL	-	-	-		-
Mercury (mg/kg)	0.16	-	-	-		-
Crude Protein (% w)	16.4	16.0	-	13.6	14.2	
Crude Fat (% dw)	-	-	-	-	-	-
Acid Detergent Fiber (ADF) (% dw)	36.7	28.7	-	31.4	35.4	-
Ash (% dw)	15.3	16.7	-	18.0	19.7	-
Total Digestible Nutrients (TDN) (% dw)	60.7	64.9	-	66.8	62.2	-
Net Energy Lactation (Mcal/lb)	0.62	0.67	-	0.69	0.64	-
Net Energy Maintenance (Mcal/lb)	0.60	0.67	-	0.67	0.62	-
Net Energy Gain (Mcal/lb)	0.36	0.38	-	0.40	0.34	-
Digestible Energy (Mcal/lb)	-	-	-	-	-	-
Metabolizable Energy (Mcal/lb)	-	-	-	-	-	-

Table 4-2: Continued

	June 2004	July 2004	August 2004	September 2004	Sufficiency Level Guidelines
Phosphorus (% dw)	0.31	0.18	0.21	0.42	0.25-0.40
Nitrogen (% dw)	2.05	2.00	1.70	2.40	-
Sodium (% dw)	0.48	0.56	0.54	0.35	-
Calcium (% dw)	1.80	1.86	1.95	1.96	1.9-2.5
Magnesium (% dw)	0.55	0.58	0.60	0.50	0.35-050
Potassium (% dw)	3.42	3.19	3.34	2.83	2.0-3.0
Iron (mg/kg)	6,513	7,150	9,695	8,489	50-150
Sulfur (% dw)	0.37	0.33	0.21	0.56	0.25-0.50
Zinc (mg/kg)	37	48	46	92	20-40
Copper (mg/kg)	19	27	33	25	5-15
Boron (mg/kg)	-				10-30
Manganese (mg/kg)	355	420	509		30-100
Cadmium (mg/kg)					-
Chromium (mg/kg)					-
Arsenic (mg/kg)					-
Lead (mg/kg)					-
Selenium (mg/kg)					-
Mercury (mg/kg)					-
Crude Protein (% w)	12.8	12.5	12.2	15	
Crude Fat (% dw)					-
Acid Detergent Fiber (ADF) (% dw)	34.8	37.4	35.8	36.9	-
Ash (% dw)	13.9	14.6	18.2	23.0	-
Total Digestible Nutrients (TDN) (% dw)	63.3	59.9	61.7	60.5	-
Net Energy Lactation (Mcal/lb)	0.65	0.61	0.63	0.62	-
Net Energy Maintenance (Mcal/lb)	0.63	0.59	0.61	0.60	-
Net Energy Gain (Mcal/lb)	0.35	0.35	0.33	0.36	-
Digestible Energy (Mcal/lb)					-
Metabolizable Energy (Mcal/lb)					-

Pest Control

While there are several arthropod pests associated with water hyacinths, those most prevalent include, in order of impact upon productivity:

- The hyacinth weevil, of which there are two species—*Neochetina eichhorniae* and *N. bruchi*. These are host specific grazers, indigenous to Argentina, imported in the seventies by the State of Florida for control of natural stands of water hyacinth. The adults feed on the leaves and stems at night, leaving open scars, which render the plant more vulnerable to opportunistic pests and pathogens. The adult during the daytime resides in and around the base of the plant, and can often be found near or just below the water interface among the roots. It is slow moving, which, along with its nocturnal habits, make it a poor target for predation by native predators such as dragonflies, spiders, frogs and birds. The adults are known to swarm and travel long distances to infest hyacinth stands. Swarming appears to be most prevalent in the early spring and mid summer, although this is based mostly upon experience and not upon documented studies. The adults lay eggs around the base of the stems, and the larvae, which emerge in just a few days, bore into the stem and move to the apical meristem at the core of the plant. The larvae tunnel through this germinative tissue as they consume and digest plant tissue, which seriously impacts plant viability and productivity. When the larvae pupate, they create a cocoon of root fibers, and reside near the water interface within the root mass. The total life cycle time depends to some extent upon temperature and upon species, but generally ranges from 35-65 days. In large numbers, weevils can actually cause large-scale mortality. When the number of insects exceeds 10/plant, the crop may be seriously threatened.

- The larvae of the hyacinth moth—*Sameodes albiguttalis*—can become problematic in the summer and fall months, with the caterpillar boring into the stem and causing severe damage to the plant. Fortunately, the adult moths will move during the daytime and are vulnerable to many predators, the most notable being dragonflies. Infestations of the moth appear, and then disappear rather quickly.

- The hyacinth mite—*Orthogalumnis terebrantis*—is an opportunistic grazer, which typically use the weevil scars to gain access to the plant tissue. The mites appear most prevalent in older leaves that have accumulated scars.

- Red spider mites—*Tetranychis timidus*—can often develop over extensive areas, turning the leaves a reddish tint. The infected areas are easily seen.

Management of these pests is critical for sustaining productivity. Harvesting plant biomass is the primary control mechanism, as destruction of the pests occurs with the processing and removal of the biomass, thereby serving as an emulation of predation.

Of these four pests, the hyacinth weevil is by far the most problematic. Consequently, efforts have been made to identify additional control methods. The most promising has been the use of parasitic nematodes that have evolved to target insects as hosts. Working with a consulting group that has been marketing nematodes for weevil control in the citrus industry, it was determined that two species had the best chance of success—*Heterorhabditis indica,* a species native to Florida, and *Steinernema sp, a* group which also has been noted to be ubiquitous in Florida—both being available commercially. Because it is native and moves aggressively towards its target, *H. indica* was initially selected. On February 27, 400 million nematodes were distributed in the evening through the irrigation system. The organisms were placed in solution of highly oxygenated water, and then injected into the pump suction line. It was found however that the pump impeller caused unacceptable mortality of the organisms, so a discharge feed system was developed so the impeller could be avoided. On April 5, 1.2 billion organisms were sprayed at night over both WHS™ units. This time the viability was maintained, and consequently 400 million organisms were distributed once weekly for the following three weeks. To test effectiveness, adult weevil and larvae were collected from the sprayed area and sent for examination. The examinations were inconclusive, although laboratory controlled exposure of the larvae to the nematodes did result in infection and mortality. Following the application, a noticeable drop in the weevil population was noted – from 4.63 insects/plant on 4/16/03 to 1.80 insects/plant on 5/16/03.

During Q2, spraying of the nematodes was done twice, and on both occasions both species were used --*Heterorhabditis indica* and *Steinernema sp.* This adjustment in strategy was implemented in an effort to more effectively impact adult populations, and to diversify the attack. Spraying was done once during Q3, Q4, Q5 and Q6. As noted, the nematodes have been effective in management of larvae populations. Populations of larvae and adults have been maintained at very low levels since nematode application was initiated.

Management of the other pests has also been quite effective. The hyacinth moth was expected to be susceptible to nematode infection as well, and such appears to have been the case, as the moth population remained negligible through Q6. Neither hyacinth mites nor spider mites have been problematic. Spider mites can be managed by irrigation, while harvesting prevents extensive development of available infection sites for the hyacinth mite. However, hyacinth mites were noted more frequently during Q2 and Q3. Pest control is an important component of the WHS™ operation, and significant opportunities exist to enhance performance of WHS™ treatment units through improved management strategies.

There are a limited number of pathogens associated with water hyacinths, the most common being the fungus *Cercospera rodmanii*. *Cercospera* is an opportunist, and can typically be avoided by maintaining plant health. This pathogen has not been observed within the WHS™ units during the entire POR..

Two issues which have emerged regarding the use of nematodes for weevil control-- the permitting requirements and the possibility of their release into native hyacinth stands, and subsequent impacts upon the control offered by the weevils in these stands. HydroMentia has worked with Integrated Biocontrol Systems of Greendale, Indiana for both obtaining commercially prepared nematodes and for technical consultation. The principle scientist with this group is Dr. James Cate, who was on the faculty of Texas A&M, and a recognized researcher and expert in the use of nematodes for biological control of pest insects. HydroMentia has also consulted with the University of Florida's IFAS research station in Lake Alfred through Dr. Harold Browning and Dr. Larry Duncan, both experts in this field.

Regarding permitting needs, other than the commercial licenses for selling nematodes for this purpose, no other regulatory requirements exist relative to use of the specified nematodes. This was noted in Microbial Insecticides Circular EY-275 of 1999 issued by the University of Florida IFAS Extension Service, as written by R. Weinzieri, T.Henn and P.G. Koehler.

With the exception of insecticidal products containing nematodes, microbial insecticides are regulated by United States Environmental Protection Agency (US EPA). Nematodes used for insect control are multicellular parasites and predators and are not regulated by US EPA.

Regarding the possibility of nematodes escaping the system, Dr. Cates offered the following:

….Nematodes do not float and will sink to the bottom in 30-45 minutes. It would take a 50 mesh screen or finer to filter them out of the water. The nematodes that are working for you (HydroMentia) are the ones that get applied to the plant and fall into cracks, crevices…and other above water parts of the plant. They will drown if left in water for more than 3-4 hours…they can live for 4-10 months in –oxygenated water and refrigerated at 35 to 50 degrees F.

….H indica and S. carpocapsae are already in the soil naturally in Florida. If insect parasitic nematodes were a threat to this biological control of the water hyacinth, they would have killed off the weevils a long time ago. In the wild, there is no way that the insect parasitic nematodes would have

the opportunity to attack the weevil in an aquatic environment.

Dr. Duncan added comments:

I don't know how your system works specifically, but I suspect a few nematodes are likely to exit your ponds, whereas most will sink to the bottom and die. Those that are released from your system may even kill a few insects. However, they will not persist in large enough numbers to threaten non-target beneficial insects. These kinds of nematodes are in virtually all habitats and there is no evidence that introduced species have displaced other nematodes species or otherwise produced significant non-target effects.

It is noteworthy that the facility has in place a 10-micron screen, which would essentially prevent any escape of rogue nematodes. But even without this precaution, it does not appear that using these nematodes poses a threat to populations of weevils outside a MAPS facility.

ALGAL TURF SCRUBBER® (ATS™)

Biomass Production and Harvesting

At the initiation of operations there was modest, but noticeable development of algae biomass on the ATS™ units. However, as operations proceeded through the month of February and into March, a loss of production was observed, and it became evident that there were environmental factors, which were inhibiting algal biomass production. Understandably, this lack of production resulted in negligible water treatment contribution by the ATS™ over this time period up to mid-March, as previously noted.

Investigations into the reasons for low productivity within the ATS™ were initiated in mid February. Three major factors were considered during these investigations:

- Deficiencies of one or more essential elements.
- Toxic influences created by elevated pH associated with the recycle program
- Toxic influences from allelopathic substances associated with the WHS™ units

It should be noted that the S-154 ATS™ operation during the Q1 – Q3 period represented the first ATS™ treatment unit operated with internal recycling. Based on performance of the ATS™ system following elimination of internal recycling which occurred at the start of Q4, many of the algal production issues pertaining to the Q1 – Q3 period may be an artifact of the internal recycling operation.

Nutrient Supplementation

HydroMentia personnel conferred with Dr. J. Benton Jones about this matter, as well as Dr. Walter Adey, Dr. Ramesh Reddy, and Tom DeBusk. Dr. Jones suggested that the high pH was likely impacting the algae, largely because of impacts upon the availability of essential trace minerals. In addition, it was hypothesized that the WHS™ units may be stripping critical nutrients, such as iron, manganese, zinc and even ortho-phosphorus and nitrogen. Tests on individual floways provided indication that nitrogen supplementation, combined with trace mineral supplementation and acid addition for pH adjustment resulted in improved productivity. By the end March a supplementation program had been fully implemented that included the following:

- Hydrochloric (Muriatic) acid 35% (10 gal/day)
- Potassium nitrate (15 lb/day)
- Ferrous sulfate (6.7 lb/day)
- Zinc sulfate (0.06 lb/day)
- Manganese sulfate (2 lb/day)
- Etibor (boron) (0.03 lb/day)

- Copper sulfate (0.04 lb/day)

This program was amended in April to include an additional 10 gallons per day of muriatic acid. During Q2 slight adjustments were made to the supplementation program

- Hydrochloric (Muriatic) acid 35% --20 gal/day until 6/17/03, reduced to 17 gal/day until 7/7/03, at which time it was returned to 20 gal/day
- Potassium nitrate (15 lb/day until 7/7/03 then increased to 21 lb/day)
- Ferrous sulfate (7.5 lb/day)
- Zinc sulfate (0.06 lb/day)
- Manganese sulfate (2 lb/day)
- Etibor (boron) (0.03 lb/day)
- Copper sulfate (0.04 lb/day)

During Q3, additional adjustments were made.

- On 10/13/03 the addition of acid was increased to 30 gallons per day
- On 8/18/03 sodium bicarbonate was added at the rate of 350 pounds/week
- On 10/20/03 sodium bicarbonate was increased to 700 pounds/week
- Reduction of Ferrous Sulfate to 5.7 lb/day

During Q4 and Q5, further adjustments were made.

- On 11/3/03 the addition of acid and sodium bicarbonate was terminated and the ATS™ effluent recycling also terminated.
- On 1/5/04 all nitrogen supplementation was terminated, and was reactivated in March, 2004 with about 0.2 lbs/day.

Algae production was initially monitored using set 0.25 m^2 “clip plots” on a diagonal across each ATS™ Unit—or control grid method. Each week the excess growth was removed from these “plots”, dried and weighed, in an emulation of harvesting. From this information, a production rate was calculated as dry-g/m^2-day. Based upon field observations during early April when algae production began in earnest, it appeared that this procedure was underestimating production. Consequently a second procedure was implemented in April. This involved selection of set grid areas in the higher upstream production areas for each floway, and then, as with the WHS™, determining percent coverage, with the product representing a production rate—referred to as the floway coverage method within Figures 4-6 and 4-7. A third calculation of productivity was made by monitoring harvest. Eventually the control grid method was eliminated. During Q6, only the harvest method was used.

Harvesting the algae involves two procedures during Q1 through Q3—the collection of filamentous algae on the Duperon rake with a ¼“ bar screen and the collection of smaller particles upon the Hydrotech microscreen with a 10 micron screens. For Q4 through Q6, with increased flows, it was not possible to capture all of the smaller particles through the microscreen, as it is designed to handle only about 50 percent of the higher loading rate study design flows. Consequently, a portion of these smaller particles were by-passed through flow diversion and were not captured. They were however, as described within Section 3, quantified through the flow and water quality sampling program.

Harvesting of filamentous algae was done by using the ATV’s (four-wheelers) to pull a drag (a chain ballasted geotextile about 20 feet wide) down each floway. The drag dislodges excess filamentous algae, which can be moved down the floway until it is deposited in the effluent flume, which carries the material to the Duperon Flex-Rake. Harvesting is typically performed such that the entire system is harvested once weekly. The wet harvest is weighed on a calibrated platform scale, and then samples taken for moisture determination. About one hour is required to harvest each event. Harvesting is done on Tuesdays and Fridays. During these harvest sessions, a considerable amount of sloughed unicellular algae is also moved into the harvest flume. This material passed through the rake and was removed by the microscreen during Q1 through Q3. As mentioned, a portion was by-passed during Q4 and Q5 because of the higher hydraulic loading rates. The microscreen also removes algae from the flumes continuously as it intercepts the effluent just before it is sampled and flow measured at the effluent Parshall flume.

When the head differential across the microscreen reaches approximately 8 inches, it is automatically backwashed. The backwash material is then pumped into the dewatering system, and recovered and weighed. Initially the backwash was recovered weekly. However material accumulation was extensive in April, making it more difficult to recovery the material on a weekly basis (the approved Monitoring Plan includes requirements for only quarterly recovery of this material). To facilitate an easier, more effective method of collecting and monitoring the backwash material, at the end of Q1 several 8 x 5 x 5 filter bags were fabricated of geotextile and placed in the dewatering bed. This allows the material to thicken more effectively. It is intended to facilitate a weekly collection when practical, which will be helpful in establishing general trends and fluctuations in microscreen harvest rates.

For Q1, harvest from the two ATS™ floways were collected together, disallowing any distinction between the two ATS™ treatment units— ATS™-North being at 2% slope, ATS™-South at 1.5% slope. During Q2 and Q3, harvest events were isolated between the two ATS™ Units, so Duperon Flex Rake harvest volumes can be recorded per ATS™ Unit. It is not practical however to distinguish individual floway contributions to the microscreen, and the assumption was continued that each floway contributes per the relative percentage of rake harvest.

Generally the higher sloped ATS™-North appeared to be developing a more “luxuriant” biomass, but this is not shown from data collection, as seen in Figures 4-6 and 4-7. The data noted in the graphs clearly shows the impact of the disruptive period, with the high harvest related values associated with the extensive sloughing of algae tissue.

During Q3, with the addition of a increased volume of acid to reduce elevated influent pH associated with ATS™ internal recycling, and the supplementation with sodium bicarbonate, productivity as determined through harvest quantity increased somewhat in both floways, indicating a positive response to additional available carbon. During Q4 the north floway was shutdown, and flow recycling eliminated, while process flow was doubled. This was done to increase phosphorus loading to the ATS™ system, with the additional benefit intent of reduced influent pH levels. Production on the reduced area floway would be expected to approximate that documented for the two floways together if carbon were the growth-modulating component. This is generally reflected within Figure 4-7, in which the areal rate of production during Q4–Q6 based upon harvest was 4.16 dry-g/m^2-day, while it was estimated at 1.70 dry-g/m^2-day based upon harvest for Q1 through Q3. This indicates that there might be a production limit, regardless of growing area, based upon some available nutrient, such as carbon. In addition, the availability and accessibility of carbon might well relate to the LHLR. If the harvest over the period, including the diverted harvest is considered, about 8,573 dry pounds of algae were harvested over 276 days of Q1 through Q3, or 31.06 pounds daily harvest as an average over the process area of 8,311 m^2. During Q4-Q6, over 323 days, about 5,787 pounds of algae were harvested or diverted, or about 17.91 pounds daily harvest as an average over an average process area of 2,739 m^2. As the growing area during Q4 through Q6 was less than 50 percent of Q1 through Q3, this provides further indication that production is not seriously influenced by area or time, at least within the context of these two scenarios, but rather is likely correlated with some other factor, such as nutrient limitation, which may relate to concentration or general availability. Nutrient availability can be a function of the nutrient species; other water quality factors; or diffusion related factors, such as velocity and turbulence. The issue of boundary layer disruption, and the reduction of impediments to nutrient diffusion and access at the cell wall is explored and discussed within the report on the independent single-stage ATS™ floways, and is discussed in more detail within Section 5 of this report.

The second stage ATS™ floways, which served as the secondary treatment component to the primary treatment WHS™ unit, received flows at a rate of about 2.2 gallons/ minute-foot of floway width during the first three quarters and 7.5 gallons/minute-foot of flowway width during Q4 through Q6. This flow parameter is refered to as the linear hydraulic loading rate or LHLR for this report. The LHLR, which is related to flow velocity and turbulence is the central variable within the study of the independent ATS™ single stage floways, as discussed within a separate report. There is included in the report on these independent single stage ATS™ floways data that provides indication that substantial production enhancement can be solicited through an increase of LHLR to about 20 gallons/minute-ft.

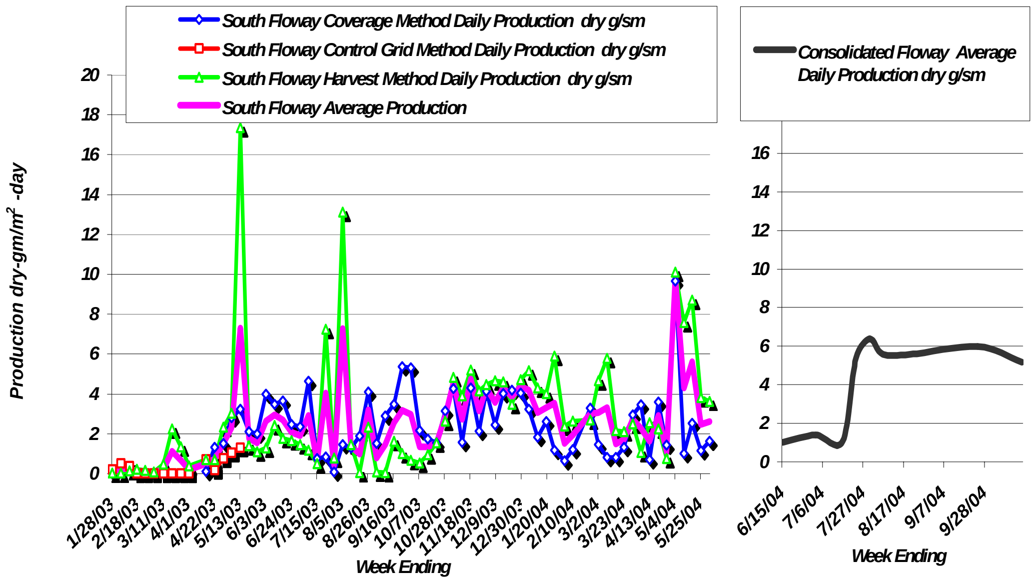
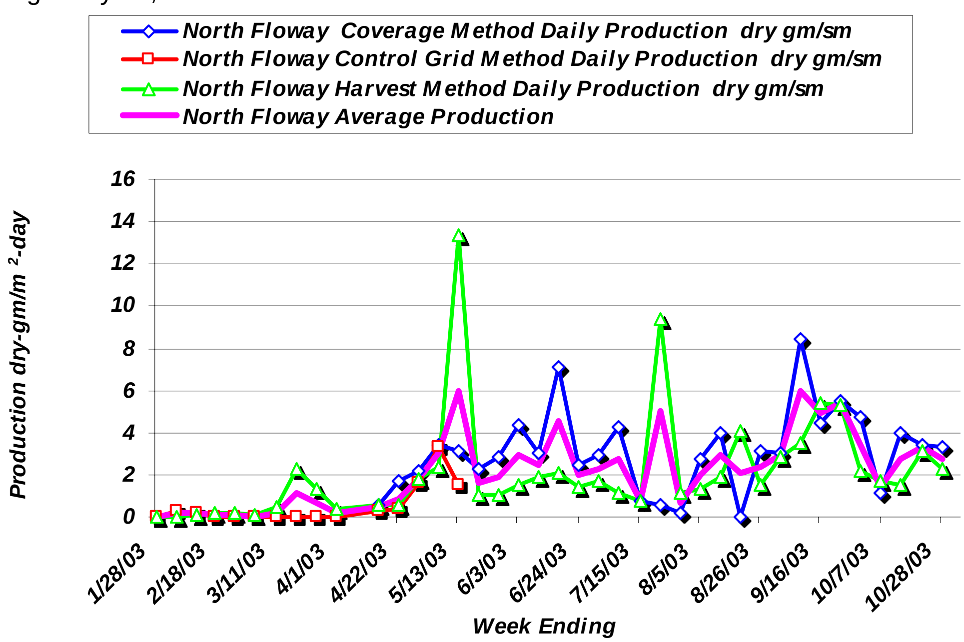


Figure 4-7: Comparative calculated production rates for ATS™ – South for the period January 27, 2003 through May 31, 2004



Note: The north ATS™ floway was taken out of service on 11/3/04 at the beginning of Q4.

Figure 4-8: Comparative calculated production rates for ATS™ – North for the period January 27, 2003 through November 3, 2003.

Grab water quality samples were taken from each floway during Q1 through Q3. The results of these grab samples are noted in Table 4-3. The data provide support to slightly higher levels of treatment associated with the higher slope unit (North), but the difference may be small enough to be statistically insignificant.

In reviewing Table 4-3, several trends are noted. The percent difference between the WHS™ and the ATS™ Effluent Post-Microscreen effluent grab is an indicator of total ATS™ treatment. The percent difference between the ATS™ Pre-Microscreen and ATS™ Post-Microscreen indicates the general contribution of the microscreen. It is estimated that the ATS™ unit prior to microscreening, removed about 6 ppb total phosphorus as an average during Q1. This increased to 118 ppb as an average for Q2, and 76 ppb for Q3, or an average of 67 ppb for the total period. During Q1, another 41 ppb was removed through the microscreen. This decreased to 26 ppb during Q2, and then returned to 41 ppb for Q3, or an average of 58 ppb for the total period. Therefore the total ATS™ system removal averaged 47 ppb total phosphorus removal during Q1, with the microscreen accounting for 87% of this, largely because of the predominance of diatoms and desmids. The total ATS™ system removal averaged 143 ppb total phosphorus removal during Q2 and 133 ppb during Q3, with the microscreen contribution reduced to 18% of this amount for Q2 and increasing to 31% for Q3. For the three quarter POR, the total ATS™ system removal averaged 107 ppb, with 38% of this removal attributable to the microscreen. This analysis could not be continued through Q4 and Q5 because of the hydraulic overloading of the microscreen as discussed previously.

During Q1, as noted previously, the microscreen was the more dominant harvesting mechanism, accounting for nearly 92% of the ATS™ harvested phosphorus. During Q2 however, this was reversed, with the Duperon Flex-Rake, through capture of filamentous algae, becoming the dominant harvesting mechanism, removing 56% of the ATS™ harvested phosphorus. The Flex-Rake would have been even more dominant, had it not been for the extensive amount of sloughed algae, which tended to pass through the rake into the microscreen during the disruptive period. During Q3, the Flex-Rake accounted for 83% of the harvested phosphorus, with the microscreen at 17%. For the three quarter POR, the Flex-Rake provided removal of 43% of the harvested phosphorus, with the microscreen providing 57%. During Q4 through Q6, the microscreen and the by-passed algae accounted for 64% of 29.07 pounds of phosphorus accounted for in algae.

Table 4-3: Comparative total phosphorus results for ATS™ grab samples for the period January 27, 2003 through November 3, 2003

Week Ending	WHS™ Effluent North & South Composite Grab sample TP (ppb)	North - ATS™ Pre-Microscreen Grab sample TP (ppb)	South - ATS™ Pre-Microscreen Grab sample TP (ppb)	ATS™ Effluent Post-Microscreen Grab Sample TP (ppb)
2/3/03	110	130	110	87
2/10/03	68	99	99	64
2/17/03	120	130	140	88
2/24/03	100	120	120	68
3/3/03	86	140	150	67
3/10/03	150	180	210	81
3/17/03	130	130	170	144
3/24/03	180	96	100	70
3/31/03	210	150	160	82
4/7/03	210	160	150	100
4/14/03	150	41	120	93
4/21/03	53	51	52	64
4/28/03	66	55	52	49
5/5/03	74	37	33	43
5/12/03	110	67	57	33
5/19/03	180	58	130	55
5/26/03	160	51	54	37
6/2/03	150	55	60	38
6/9/03	170	49	53	36
6/16/03	220	50	58	30
6/23/0	220	100	99	53
6/30/03	200	66	73	52
7/7/03	330	140	150	87
7/14/03	500	240	250	120
7/21/03	320	210	220	200
7/28/03	220	120	120	142
8/4/03	190	85	95	74
8/11/03	190	84	84	61
8/18/03	180	75	70	52
8/25/03	280	150	150	94
9/1/03	240	84	100	67
9/8/03	260	160	180	155
9/15/03	280	210	170	109
9/22/03	160	150	160	70
9/29/03	200	130	140	83
10/6/03	180	ND	ND	61
10/13/03	250	210	230	71
10/20/03	240	170	160	89
10/27/03	170	140	130	69
11/3/03	160	99	100	87
Mean	185	115	122	78

Tissue Quality

The quality of the algae was monitored throughout the POR, as with the hyacinths, with monthly composites for the rake harvest, and a quarterly composite for the microscreen backwash solids. The results of these analyses are noted in Table 4-4.

During all six quarters, samples from the backwash were taken regularly and composited, and sent to Midwest Laboratories for analysis at the end of each quarter. The ATS™ harvest record for both the microscreen and the Duperon Flex-Rake, as well as the diverted harvest during Q4 through Q6, are noted in Section 3. Monthly samples for the algae and the microscreen backwash are presented in Table 4-4. In addition, weekly samples of algae were taken for phosphorus until the end of February 2004, as shown in Table 4-5.

The tissue quality noted for February 2003 is suggestive of mineral deficiencies. There is a marked improvement in March, continuing through May, 2004, as a result of the mineral supplementation and pH adjustment program. It is evident that microscreen backwash, with the high ash content and increased levels of metals and salts, represents a blend between sloughed algae and precipitated minerals. This is somewhat true of the rake-harvested algae as well, which showed higher ash and lower fiber content than the hyacinths. The high ash indicates that the algae likely serves as a capture site for precipitated salts, and as noted previously, will solicit phosphorus precipitation within the vicinity of the higher pH algal cell wall microenvironment.

During Q2, the filamentous algae tissue showed a significant increase in iron and manganese content, likely as a result of excess nutrients added through supplementation. Iron addition to the ATS™ was reduced during Q2 and further reduced during Q3. It was eliminated totally during Q4. Tissue phosphorus content increased also over Q2, suggesting contribution through precipitation of salts, some of which is likely associated with the excess iron, as noted previously. Phosphorus content was reduced through Q3, and fell further during Q4 as a result of lower influent phosphorus concentrations. The tissue phosphorus content was noted to increase again during the latter part of Q5, as phosphorus concentrations increased.

The backwash was higher in manganese during Q2, but lower in iron as compared to Q1. However, the iron and manganese content returned to higher levels during Q3 within the backwash. The phosphorus content of the backwash was slightly lower during Q2, as compared to Q1, and was further reduced during Q3 through Q6.

The algae tissue is higher in protein than the water hyacinths; lower in fiber; and shows slightly higher metals content, although not at levels of concern regarding is use as a feed product. The algae harvest, properly processed would likely be considered a high value feed additive.

Table 4-4: Quarterly composite algae samples for the period January 27, 2003 through October 18, 2004

	Q1 Microscreen Backwash	Q2 Microscreen Backwash	Q3 Microscreen Backwash	Q4 Microscreen Backwash	Q5 Microscreen Backwash	Q6 Microscreen Backwash	Sufficiency Level Guidelines
Phosphorus (% dw)	0.52	0.47	0.44	0.39	0.40	0.12	0.25-0.40
Nitrogen (% dw)	3.22	2.40	2.96	2.58	2.53	1.21	-
Sodium (% dw)	0.12	0.39	0.10	0.14	0.25	0.04	-
Calcium (% dw)	1.92	3.74	2.96	5.25	4.76	3.43	1.9-2.5
Magnesium (% dw)	0.94	0.50	0.76	1.79	1.52	1.31	0.35-050
Potassium (% dw)	0.20	0.44	0.21	0.24	0.24	0.08	2.0-3.0
Iron (mg/kg)	27,896	4,134	49,533	25,223	57,253	29,705	50-150
Sulfur (% dw)	0.65	0.86	0.49	0.45	2.82	2.08	0.25-0.50
Zinc (mg/kg)	247	685	391	120	214	132	20-40
Copper (mg/kg)	35	171	76	38	73	50	5-15
Boron (mg/kg)	27	-	17	32	34	6.0	10-30
Manganese (mg/kg)	400	8,313	17,109	3,659	819	341	30-100
Cadmium (mg/kg)	0.44	BDL	BDL	BDL	0.18	BDL	-
Chromium (mg/kg)	25	52	21	11	24	15	-
Arsenic (mg/kg)	21.4	9.3	BDL	BDL	BDL	BDL	-
Lead (mg/kg)	26.3	8.4	115	10.8	32.3	5.32	-
Selenium (mg/kg)	1.06	1.45	BDL	BDL	12	BDL	-
Mercury (mg/kg)	0.18	0.06	0.12	0.07	0.10	0.12	-
Crude Protein (% dw)	-	-	-	16.1	15.8	7.69	-
Acid Detergent Fiber (ADF) % dw	-	-	-	43.2	30.8	60.9	-
Ash % dw	52.7	65.0	-	58.2	-	77.5	-
Total Digestible Nutrients (TDN) % dw	-	-	-	-	67.4	33.1	-
Net Energy Lactation (Mcal/lb)	0.72	-	-	-	0.70	0.31	-
Net Energy Maintenance (Mcal/lb)	-	-	-	-	0.68	0.27	-
Net Energy Gain (Mcal/lb)	-	-	-	-	0.41	0.09	-

Table 4-4: Continued

Algae Tissue	Feb	March	April	May	Sufficiency Level Guidelines
Phosphorus (% dw)	0.12	0.47	0.57	0.49	0.25-0.40
Nitrogen (% dw)	1.09	4.45	4.64	5.20	-
Sodium (% dw)	0.07	0.28	0.31	0.35	-
Calcium (% dw)	0.63	1.81	2.33	1.89	1.9-2.5
Magnesium (% dw)	0.16	1.17	0.49	0.58	0.35-050
Potassium (% dw)	0.23	2.51	3.01	2.58	2.0-3.0
Iron (mg/kg)	3,292	20,365	21,072	24,991	50-150
Sulfur (% dw)	0.13	1.30	1.68	1.56	0.25-0.50
Zinc (mg/kg)	22	208	175	186	20-40
Copper (mg/kg)	12	47	72	39	5-15
Boron (mg/kg)	-	-	46	-	10-30
Manganese (mg/kg)	-	1,257	4,296	10,896	30-100
Cadmium (mg/kg)	-	-	0.18	-	-
Chromium (mg/kg)	-	-	11	-	-
Arsenic (mg/kg)	-	-	21.4	-	-
Lead (mg/kg)	-	-	17.9	-	-
Selenium (mg/kg)	-	-	1.24	-	-
Mercury (mg/kg)	-	-	0.10	-	-
Crude Protein (% dw)	17.4	26.6	29.0	33.90	-
Acid Detergent Fiber (ADF) % dw	74.7	25.5	20.1	17.2	-
Ash % dw	80.30	26.9	26.8	21.80	-
Total Digestible Nutrients (TDN) % dw	17.4	73.5	79.6	82.9	-
Net Energy Lactation (Mcal/lb)	-	0.76	0.83	0.87	-
Net Energy Maintenance (Mcal/lb)	-	0.75	0.83	0.87	-
Net Energy Gain (Mcal/lb)	-	0.49	0.56	0.58	-

Table 4-4: Continued

Algae Tissue	June	July	August	September	October	Sufficiency Level Guidelines
Phosphorus (% dw)	0.56	0.73	0.71	0.64	0.49	0.25-0.40
Nitrogen (% dw)	4.94	4.46	4.83	4.37	4.46	-
Sodium (% dw)	0.34	0.29	0.24	0.17	0.16	-
Calcium (% dw)	1.93	1.92	1.88	2.20	2.27	1.9-2.5
Magnesium (% dw)	0.66	0.67	0.61	0.62	0.74	0.35-050
Potassium (% dw)	2.19	1.64	1.88	1.77	1.81	2.0-3.0
Iron (mg/kg)	33,841	45,449	39,580	39,199	38,816	50-150
Sulfur (% dw)	1.45	1.19	0.83	0.75	0.64	0.25-0.50
Zinc (mg/kg)	258	294	254	255	236	20-40
Copper (mg/kg)	103	84	51	58	53	5-15
Boron (mg/kg)		78	-	-	67	10-30
Manganese (mg/kg)	14,506	18,006	20,971	19,893	16,901	30-100
Cadmium (mg/kg)	-	BDL	-	-	BDL	-
Chromium (mg/kg)	-	12	-	-	15	-
Arsenic (mg/kg)	-	6.6	-	-	BDL	-
Lead (mg/kg)	-	BDL	-	-	5.9	-
Selenium (mg/kg)	-	0.63	-	-	BDL	-
Mercury (mg/kg)	-	0.06	-	-	0.12	-
Crude Protein (% dw)	30.9	27.9	27.8	28.1	27.9	-
Acid Detergent Fiber (ADF) % dw	16.6	21.0	23.0	28.2	28.8	-
Ash % dw	29.9	29.4	24.1	32.5	33.7	-
Total Digestible Nutrients (TDN) % dw	83.6	78.6	76.3	70.4	69.7	-
Net Energy Lactation (Mcal/lb)	0.88	0.82	0.80	0.73	0.72	-
Net Energy Maintenance (Mcal/lb)	0.87	0.81	0.79	0.71	0.71	-
Net Energy Gain (Mcal/lb)	0.58	0.55	0.53	0.45	0.49	-

Table 4-4: Continued

	November	December	January 2004	February 2004	March 2004	April 2004	May 2004	Sufficiency Level Guidelines
Phosphorus (% dw)	0.59	0.48	0.50	0.43	0.54	0.61	0.46	0.25-0.40
Nitrogen (% dw)	4.66	3.17	3.72	3.90	3.07	3.69	3.72	-
Sodium (% dw)	0.18	0.22	0.22	0.29	0.24	0.19	0.15	-
Calcium (% dw)	2.44	6.98	6.91	2.75	2.06	2.44	2.13	1.9-2.5
Magnesium (% dw)	0.89	3.36	3.23	1.18	0.89	0.94	0.84	0.35-050
Potassium (% dw)	2.06	1.25	1.31	3.04	3.35	2.63	2.11	2.0-3.0
Iron (mg/kg)	39,007	22,906	19,497	21,309	20,384	34,628	37,632	50-150
Sulfur (% dw)	0.81	0.60	0.60	1.37	1.56	1.3	1.12	0.25-0.50
Zinc (mg/kg)	182	100	81	55	43	62	74	20-40
Copper (mg/kg)	77	30	45	19	16	25	65	5-15
Boron (mg/kg)	-	-	25.6	-	20	-	-	10-30
Manganese (mg/kg)	12,507	3,554	2,984	2,488	1,418	2,044	5,646	30-100
Cadmium (mg/kg)	-	-	BDL	-	-	-	-	-
Chromium (mg/kg)	-	-	22	-	-	-	-	-
Arsenic (mg/kg)	-	-	BDL	-	-	-	-	-
Lead (mg/kg)	-	-	BDL	-	-	-	-	-
Selenium (mg/kg)	-	-	BDL	-	-	-	-	-
Mercury (mg/kg)	-	-	0.07	-	-	-	-	-
Crude Protein (% dw)	29.1	19.8	23.3	24.4	-	23.1	23.3	-
Acid Detergent Fiber (ADF) % dw	22.5	20.4	7.3	24.4	-	27.0	28.2	-
Ash % dw	32.0	45.2	36.6	31.2	-	35.0	37.7	-
Total Digestible Nutrients (TDN) % dw	76.9	79.3	94.2	74.7	-	71.8	70.4	-
Net Energy Lactation (Mcal/lb)	0.80	0.83	0.99	0.78	-	0.74	0.73	-
Net Energy Maintenance (Mcal/lb)	0.79	0.82	1.00	0.77	-	0.73	0.71	-
Net Energy Gain (Mcal/lb)	0.54	0.55	0.66	0.51	-	0.47	0.45	-

Table 4-4: Continued

	June 2004	July 2004	August 2004	September 2004	Sufficiency Level Guidelines
Phosphorus (% dw)	0.41	0.42	0.50	0.94	0.25-0.40
Nitrogen (% dw)	4.46	3.14	4.21	3.49	-
Sodium (% dw)	0.23	0.26	0.35	0.11	-
Calcium (% dw)	1.53	1.73	1.79	1.62	1.9-2.5
Magnesium (% dw)	0.43	0.45	0.39	0.42	0.35-050
Potassium (% dw)	2.00	1.16	3.41	0.78	2.0-3.0
Iron (mg/kg)	38,993	59,717	30,763	34,148	50-150
Sulfur (% dw)	1.05	0.90	1.77	0.73	0.25-0.50
Zinc (mg/kg)	135	78	85	107	20-40
Copper (mg/kg)	46	14	65	36	5-15
Boron (mg/kg)					10-30
Manganese (mg/kg)	5,577	2,243	2,340	4,080	30-100
Cadmium (mg/kg)					-
Chromium (mg/kg)					-
Arsenic (mg/kg)					-
Lead (mg/kg)					-
Selenium (mg/kg)					-
Mercury (mg/kg)					-
Crude Protein (% dw)	27.9	19.6	28.8	21.8	-
Acid Detergent Fiber (ADF) % dw	28.6	28.4	31.0	36.6	-
Ash % dw	30.0	43.2	26.9	48.7	-
Total Digestible Nutrients (TDN) % dw	67.7	70.2	67.2	60.8	-
Net Energy Lactation (Mcal/lb)	0.70	0.73	0.69	0.62	-
Net Energy Maintenance (Mcal/lb)	0.68	0.71	0.68	0.60	-
Net Energy Gain (Mcal/lb)	0.42	0.45	0.41	0.36	-

Table 4-5: Weekly algae grab tissue samples for phosphorus for the period January 27, 2003 through February 28,2004.

Date	ATS™ Composite Grab Tissue Sample TP (% dw)	Date	ATS™ Composite Grab Tissue Sample TP (% dw)	Date	ATS™ Composite Grab Tissue Sample TP (% dw)	Date	ATS™ Composite Grab Tissue Sample TP (% dw)
1/28/03	0.81	5/26/03	0.54	9/8/03	0.63	12/21/04	0.35
2/4/03	0.21	6/2/03	0.48	9/15/03	0.70	12/28/04	0.52
2/11/03	0.37	6/9/03	0.56	9/22/03	0.53	1/4/04	0.57
2/25/03	0.29	6/16/03	0.77	9/29/03	0.53	1/11/04	0.53
3/4/03	0.18	6/23/03	0.62	10/6/03	0.47	1/18/04	0.53
3/11/03	0.39	6/30/0	0.61	10/13/03	0.56	1/25/04	0.52
3/18/03	0.41	7/7/03	0.78	10/20/03	0.54	1/31/04	0.59
3/25/03	0.51	7/14/03	0.79	10/27/03	0.51	2/7/04	0.51
4/4/03	0.52	7/21/03	0.70	11/3/03	0.57	2/14/04	0.43
4/11/03	0.72	7/28/03	0.73	11/10/04	0.57	2/21/04	0.32
4/22/03	0.61	8/4/03	0.71	11/17/04	0.64	2/28/04	0.34
4/29/03	0.52	8/11/03	0.71	11/24/04	0.62		
5/5/03	0.49	8/18/03	0.63	12/1/04	0.68		
5/12/03	0.50	8/25/03	ND	12/7/04	0.60		
5/19/03	0.34	9/1/03	0.65	12/14/04	0.63		

Species Composition

The algal community within the ATS™ during Q1 was dominated by the filamentous green algae, *Cladophora sp.,* with other green algae, including desmids, as represented by *Pediastrum sp., Cosmarium sp, Coelastrum sp., Hydrodictyon sp., Spirogyra sp* and *Scenedesmus sp.;* a variety of diatoms, the most common being *Melosira sp., Navicula sp. Synedra sp. and Cyclotella sp.* Also observed was the red algae *Compsopogan,* and the Chrysophyceae, *Synura sp. Navicula sp.* is most predominant in the downstream areas of the floways, where pH was highest, and nutrient availability is lowest. During Q2 these patterns continued until the disruptive period, at which time most of the standing crop was lost. As the floways recovered, diatoms again were first noted, followed by a development of *Cladophora sp.* Also the cyanobacteria *Anabaena sp.* was noted during this recovery period. Throughout Q3 *Cladophora sp.* and *Navicula sp*. remained dominant, although by October both *Hydrodictyon sp.* and *Spirogyra sp.* were noted to contribute to the filamentous portion of the algal turf, perhaps in response to cooler conditions. The cyanobacteria presence was negligible after system recovery.

During Q4 through Q6 the algal community remained similar to that noted during Q2 and Q3, even though the process flow strategy had been adjusted through termination of internal recycling. Generally, three green algae appeared to be predominant, these being *Cladophora sp., Hydrodictyon sp.,* and a new species, *Rhizoclonium sp.* During the cooler months, *Cladophora sp.* relinguished dominance to the other two species, appearing again as the most prevalent algae by April 2004. In March, 2004 there was observed a presence of two cyanobacteria—*Oscillatoria sp* and *Anabaena sp*—but these disappeared by mid-April. The cyanobacteria appear to be opportunists that take advantage of system disturbances, such as dry-downs during herbicide spraying or power outages. Also, cyanobacteria may gain a selective advantage during low nitrogen periods, as they often can fix atmospheric nitrogen.

Protists and invertebrate animals associated with the ATS™ include paramecium, rotifers, gastrotrichs, nematodes, amphipods and copepods. Chironomid larvae were also noted during Q3 through Q6. Vertebrates observed on the ATS™ included a few reptiles and amphibians, and a moderately large number of birds, including shore birds, such as sanderlings and sandpipers; mottled ducks and blue winged teal; and crows and grackles. Stilts and yellowlegs were observed as well during Q2, Q3 and Q4.

BIOMASS PROCESSING AND PRODUCT DEVELOPMENT

As noted, the majority of the water hyacinth biomass harvested was chopped and transported to McArthur Farms, where it was blended and fed to a group of heifers as an ingredient of a greenchop feed. About 10 lbs/day per individual were fed daily. While it is recognized that the wet hyacinth/algae material is not an optimum feed product because of the large amount of water involved, this feeding program has established general palatability of the recovered wet biomass. Previous studies conducted by the University of Florida and Florida Department of Agriculture demonstrated the palatability and feed potential of the dried hyacinth biomass.

Some of the algae harvest from the Duperon Flex-Rake was also included in the feed deliver to McArthur Farms. Both products are high in protein on a dry weight basis—15.5% for hyacinths and often over 28% for algae—and are candidates as a dried feed additive.

A relatively small fraction of the hyacinth biomass, the microscreen backwash and algae has been composted. These products are mixed with hay to add carbon and reduce moisture content. The composting process proceeded as expected, with internal temperatures exceeding 125 ^{o}C. The first batch was completed during the Q1. The quality of the first batch is summarized within Table 4-6. The high ash content is likely related partly to accumulation of wind blown sand, which made it difficult to establish a pre and post nutrient balance. A larger amount was blended as Batch #2, and it was finished during Q2. An assessment of Batch #2 is noted in Table 4-7. The Batch #2 process resulted in the solids reduction by 24% within about 95 days, retainage of nitrogen and phosphorus and the loss of 94% of the moisture. Even though the original batch had a higher than desirable moisture content, it reacted well, reaching the desired temperatures, and resulting in material stabilization. This supports the contention that chopped hyacinths and algae can be readily composted using conventional methods. Subsequent small compost batches have been produced, showing similar characteristics as noted for Batch #2.

Table 4-6: Compost characteristics for the period January 27, 2003 through May 5, 2003

Content as delivered	Finished Batch #1
Phosphorus % as P_2O_5	0.20
Nitrogen (%)	0.93
Ash (%)	61.8
Moisture (%)	18.4
Potassium (%)	0.35
Sulfur (%)	0.09
Calcium (%)	0.67
Magnesium (%)	0.12
Sodium (%)	0.05
Copper (mg/kg)	7
Iron (mg/kg)	834
Manganese (mg/kg)	54
Zinc (mg/kg)	37
pH	8.2

Table 4-7: Compost characteristics and changes for Batch #2

Content	Beginning Batch #2		Finished Batch #2	
	%	Total Pounds	%	Total Pounds
Total Weight pounds	-	52,883	-	6,589
Moisture	91	48,111	45.2	2,978
Total Dry Weight	-	4,772	-	3,611
Phosphorus dw	0.26	12.2	0.36	12.9
Nitrogen dw	2.30	110	3.21	116
Ash	-		60.2	2,174
Potassium dw	-		1.11	40
Sulfur dw	-		0.33	12
Calcium dw	-		3.72	134
Magnesium dw	-		0.55	20
Sodium dw	-		0.18	6
Iron dw	-		0.70	25
Copper dw	-		0.0013	0.005
Manganese dw	-		0.040	1
Zinc dw	-		0.011	0.40
pH units	-		8.0	-

SECTION 5. MODEL PROJECTION COMPARISONS

Actual Versus Projected Performance – Outflow Concentration Optimization Period

Design conditions and performance projections for the initial prototype design conditions, as implemented from Q1 through Q3, were presented in the Preliminary Engineering Report delivered prior to system construction. Figures 5-1 and 5-2 include the design conditions and model projections as presented within this report.

INPUTS	
Influent Average Daily Flow (mgd)	0.50
Influent Average Total Nitrogen (mg/l)	3.25
Influent Average Total Phosphorus (mg/l)	0.56
V'ant Hoff Arrhenius Coefficient	1.05
Incidental Nitrogen Removal Constant	0.00
Incidental Phosphorus Removal Constant	0.00
Average Air Temperature (degrees C)	26.00
Maximium Specific Growth Rate (1/day)	0.040
Wet Crop Density (lb/sf)	4.00
Half Rate Concentration (mg/l TN)	5.00
Growing Area (acres)	2.50
Plant Nitrogen Content (% dry weight)	2.20%
Plant Phosphorus Content (% dry weight)	0.40%
Plant percent solids	5.00%
OUTPUTS	
Standing Crop (Wet Tons)	218
Field Water Hyacinth Growth Rate (1/day)	0.017
Average Pond Depth (ft)	3.50
Hydraulic retention time (days)	5.70
Average Daily Harvest (Wet Tons)	3.6
WHS™ Effluent Total Nitrogen (mg/l)	**1.33**
WHS™ Effluent Total Phosphorus (mg/l)	**0.211**
Nitrogen Removal lb/day	7.99
Nitrogen Removal ton/yr	1.46
Nitrogen Removal Rate lb/acre-day	3.20
Phosphorus Removal lb/day	1.45
Phosphorus Removal ton/yr	0.27
Phosphorus Removal Rate lb/acre-day	0.58
Note: 50 pounds daily of potassium nitrate added to supplement nitrogen to balance n:p ratio to 6:1	

Figure 5-1: S-154 Pilot WHS™ HYADEM pre-project model projection as provided within the S-154 Preliminary Engineering Report

Depth ft	0.02
Width ft	363
Flow MGD	0.50
Flow CFS	0.77
Recycle Rate MGD	2.00
Inital Phosphorus Concentration mg/l	0.21
Inital Nitrogen Concentration mg/l	1.33
Phosphorus Content	
% dry Weight	0.45%
Nitrogen Content	
% dry Weight	2.00%

Travel Time sec	Distance ft	Flow Velocity ft/sec	Standing Crop Dry lb/sf	Specific Growth Rate 1/day	Net Dry Growth lb/day	Phosph. Uptake Rate lb/pass	Nitrogen Uptake Rate lb/pass	Influent TP mg/l	Effluent TP mg/l	Influent TN mg/l	Effluent TN mg/l
566	300	0.53	0.007	0.20	168.775	0.0050	0.0221	0.07	0.04	0.67	0.51

TOTAL AREA IN ACRES	2.50
AVERAGE DAILY HARVEST WET TONS	0.84
DAILY PHOSPHORUS REMOVAL POUNDS	0.72
ANNUAL PHOSPHORUS REMOVED TONS	0.13
DAILY NITROGEN REMOVAL POUNDS	3.41
ANNUAL NITROGEN REMOVED TONS	0.62

Note: daily harvest of 0.84 tons or 1680 lbs wet with density of 55 lb/cf or about 31 cf, need at 6" thickness and harvest once weekly, 434 sf of drain slab or 50 x 9 feet.

Figure 5-2: S-154 Pilot ATS™ pre-project model projection as provided within the S-154 Preliminary Engineering Report

Presented in Table 5-1 and within Figures 5-3 through 5-6 are the actual conditions and system performance for the ATS™-WHS™ system through Q3. From this data compilation, several observations can be offered, as listed below.

1. The system during Q1 through Q3 was operated at a phosphorus loading rate lower than design (19.12 vs. 15.54 g/m^2-yr), which is attributable some to lower flow rates and some to lower incoming total phosphorus concentrations, particularly during Q3. Accordingly, the system has demonstrated a lower phosphorus removal rate (17.76 vs. 12.76 g/m^2-yr) when compared to design. It is noteworthy that the differential between actual loading and actual removal rates was observed to be higher than the differential between actual design rates (1.36 vs. 2.78 g/m^2-yr), as shown below. The highest value of 4.27 g/m^2-yr was seen in July during the disruptive period.

	Differential between loading and removal rates as g-TP/m^2-yr
Design	1.36
Q1+Q2+Q3	**2.78**
February	1.80
March	3.27
April	2.05
May	1.22
June	1.43
July	4.27
August	2.27
September	2.63
October	1.60

2. This differential between loading and removal rates indicates that the actual performance is on the average slightly below design projections. When the average effluent concentration (79 ppb) is compared to design concentration (40 ppb), the differential of 39 ppb as an average amounts to about 1.30 g-TP/m^2-yr) at the documented average flow rate. As expected, this differential is close to the difference between actual and design loadings to removal differential. While other mechanisms and phenomenon are involved, it appears that

as an average the limits of the system are set by that fraction of the incoming phosphorus that is biologically difficult to secure, and this fraction may be just above the 40 ppb target. This "basement" concentration, (which is noted as C^* in the DMSTA model) is estimated to be above 40 ppb, but below 80 ppb for the ATS™ -WHS™ system as applied to S-154. It would be expected that this value-- C^* --will vary within each set of water quality conditions. It is likely that factors such as calcium, magnesium and iron concentrations, as well as pH and alkalinity will be influential in establishing a reasonable value, and that further refinements of system design and operations may facilitate a reduction of this "basement" concentration. This same trend is noted with nitrogen, with removal rates near design levels, but effluent concentrations well above design, indicating again a "basement" concentration, which for nitrogen appears to be just less than 1.50 mg/l as total nitrogen, most of which is organic nitrogen.

3. When phosphorus-loading rate is compared to phosphorus removal rate, a good correlation is noted as shown in Figure 5-7. For the composite three quarters a linear regression reveals an $\mathbf{r^2}$ of 0.95, with a slope (a) of 0.9935 and a y-intercept (b) of –2.3155. This high correlation coefficient is related to a degree to auto-correlation, as hydraulic loads and influent concentrations are common to both the dependent and independent variables. The same relationship is shown as percent removal (removal rate/loading rate) in Figure 5-8. Of interest is the implication that when the phosphorus loading is zero, which would be equivalent to flow with no phosphorus, or perhaps a long-term static condition, there would occur an internal regeneration of phosphorus to the water column of about 2.32 gm/m^2-yr. If a flow of 0.42 MGD is considered, this amounts to about 72 ppb. In addition, when phosphorus loading drops to about 2.33 gm/m^2-yr, there is no net removal or regeneration of phosphorus. This then would represent an equalization loading point. As the internal regeneration of phosphorus applies primarily to phosphorus stored within sediments, these impacts relate primarily to treatment systems with accumulated sediments including WHS™, EMA-STA, SAV and PSTA.

4. A linear regression analysis was done also for each individual quarter for loading rates vs. removal rates on phosphorus, as noted within Figures 5-9 to 5-11. Each quarter varies somewhat in slope and intercept, with Quarter 2 showing the greatest deviation, as noted below. Because the slope during Quarter 2 is greater than 1, there is an inference that there is an influence exerted by resolubilization of internal phosphorus stores, for at some high loading value, the removal rate exceeds loading (about 70 gm-P/m^2-yr). While this relationship might well collapse well before this loading rate is realized, there was some indication, as discussed within Sections 2 and 3, that internal phosphorus stores may have been a factor in performance during the second quarter. This is supported also by the high absolute value of the y-intercept, when compared to the other quarters, which can be interpreted as a greater potential for phosphorus regeneration from the sediments during this period.

	Slope (a)	Y-Intercept (b)	Regression Coefficient (r^2)
Q1	0.9750	-1.9340	0.977
Q2	1.0482	-3.1562	0.907
Q3	0.9068	-1.2618	0.955
Combined	0.9935	-2.3155	0.954

5. The only logical sources of this internally generated (autochthonous) phosphorus would be from redistribution to the water column from quasi-sequestered deposits, whether these are of an organic nature as adsorbed or chemically bonded phosphate, or precipitated salts of multivalent cations. This redistribution phenomenon was considered within the Preliminary Engineering Report as previously cited, with contemplated internal phosphorus sources being associated within the WHS™ as resolubilized phosphorus from organic deposits associated with sloughed tissue, and within the ATS™ as a nocturnal dissociation of calcium-phosphate complexes as pH values decline during the respiratory phase.

The loading to removal relationship expressed as a linear equation is:

$$P_R = aP_L + b \qquad \textbf{(Equation 7)}$$

Where P_R = phosphorus removal rate in g/m^2-yr
P_L = phosphorus loading rate in g/m^2-yr
a = slope, b = y intercept as g/m^2-yr

Considering that $P_R = (C_IQ_I\text{-}C_EQ_E)/A$ and
$P_I = C_IQ_I/A$

Where C_I = Influent concentration of phosphorus gm/m^3
C_E = Effluent concentration of phosphorus gm/m^3
Q_I = Influent Flow m^3/yr
Q_E = Effluent Flow m^3/yr
A = Process area m^2

Therefore the equation can be reduced to remove the contamination of the dependent variable (C_E) by the independent variable (C_I). If we identify some fraction k to apply to Q_I such that $Q_E = k\ Q_I$, then:

$$C_E = -\{[C_I\,(a-1)]/k\} – [(Ab)/(kQ_I)] \qquad \textbf{(Equation 8)}$$

Using Equation 7 and the a and b values determined from the previous Q1+Q2+Q3 linear regression, the effluent concentration can be projected from influent flow and influent concentration. The comparison of actual vs. projected effluent phosphorus concentrations using Equation 7, are shown in Figure 5-12. When five "outliers" are deleted (these being associated primarily with the disruptive period) the linear regression between actual and projected effluent concentrations results in an $r^2 = 0.27$, indicating a degree of predictability, but also indicating the significant influence of other variables.

6. While these relationships are helpful, it needs to be recognized that unlike passive wetland treatment systems, as modeled using the DMSTA, Managed Aquatic Plant Systems (MAPS) such as ATS™ and WHS™ rely significantly upon sustained plant productivity and controlled precipitation (ATS™ only), and the subsequent removal from site (RFS) through harvesting of biomass, and their modeling, design and operations need to be directed around these activities. While modeling of passive systems is oriented towards assessment of a collection of phenomenon, (many which are largely unknown), that work in combination to deposit a quasi-stable phosphorus laden peat, modeling of MAPS systems is oriented largely around the predictability of plant growth and the rate of removal of that portion of growth such that a viable, working standing crop is maintained at a stable level. Within MAPS units however, there is also the component of accretion of organic matter and precipitation of salts, hence it is important to also include within the model the influence of this process. While plant production and harvesting typically represents the major source of phosphorus removal, the storage component maintains significant influence upon modulation of water column concentrations. Because MAPS systems are much more aggressive in terms of both nutrient and hydraulic loading rates, when compared to passive systems, there may be a wider degree of variability, at least initially, when compared to passive systems, as the reaction time to adjust to changes in environmental conditions is much smaller. In exchange for this variability however, is a realization of long-term stability associated with sustained management and RFS, and greater system control and flexibility. Passive systems, which are extensive, provide a larger storage component and a greater hydraulic retention time, thereby offering initial stability as stores are filled. However, on a long-term basis, once these stores approach saturation, system capacity and performance may be challenged.

7. There is a significant philosophical difference between the engineering and operational

foundations of the two systems—MAPS (active) and STA (passive). MAPS offers sustainability and a greater degree of long term stability, while providing the most important function of RFS—i.e. actual removal and recovery of nutrients. This is accomplished through a continuous management effort, much of which is agricultural in nature. The STA type technology with significantly greater land requirement, when compared to MAPS, offers stability and predictability during the initial period of operation, and during this period demands less operational attention than a MAPS facility. However, as long as there is no RFS component, the STA unit must be viewed not as a sustained treatment system, but rather as a storage facility with a finite life. A truly objective comparison of these two approaches must include evaluation of all aspects of operations during the expected operational period; including securing and stabilizing expended facilities—i.e. STA systems that have consumed available storage. Through well designed engineering evaluations integration of the two approaches can be reviewed such that the benefits of an effective synergy can be realized. For example, reduction of incoming nutrient loads by a MAPS facility will likely extend the life and improve the ecological quality of a receiving STA, while also allowing reduction of land requirements. Similarly a MAPS downstream of an STA would likely enhance operational flexibility and provide redundancy, while accommodating a more suitable hydraulic regime within the STA, thereby rendering it more emulative of historical native wetlands.

Table 5-1: ATS™ and WHS™ pre-operation modeling water quality projections comparison with actual results Q1 through Q3.

	Model Projection	**Actual Q1+Q2+Q3 Composite**	**Actual February**	**Actual March**	**Actual April**	**Actual May**	**Actual June**	**Actual July**
Average Daily Flow Influent (MGD)	0.500	0.431	0.341	0.487	0.449	0.437	0.479	0.438
Average Daily Flow Effluent (MGD)	0.500	0.416	0.315	0.463	0.377	0.358	0.463	0.444
Influent TP (ppb)	560	493	381	558	683	572	517	432
Effluent TP (ppb)	40	79	71	97	72	41	71	124
Average Daily Load TP (lbs)	2.34	1.63	1.08	2.27	2.56	2.08	2.06	1.58
Influent TN (mg/l)	3.25	4.47	3.03	3.53	4.27	4.37	4.01	4.49
Effluent TN (mg/l)	0.51	1.68	1.60	1.76	1.73	1.75	1.44	1.66
Average Daily Load TN (lbs)	15.87	14.46	8.62	14.34	15.99	15.93	16.02	16.40
Average Daily Removal TP lb/day (%)	2.17 (92.7%)	1.42 (84.0%)	0.89 (82.4%)	1.90 (83.7%)	2.33 (91.2%)	1.96 (94.1%)	1.79 (86.7%)	1.12 (70.9%)
Average Daily Removal TN lb/day (%)	11.43 (84.4%)	9.72 (61.3%)	4.42 (51.3%)	7.54 (52.6%)	10.55 (66.0%)	10.70 (67.2%)	10.27 (64.1%)	10.25 (62.5%)
TP Areal Loading Rate (g/m^2-yr)	19.12	15.54	10.32	19.47	22.70	16.51	13.44	14.24
TP Areal Removal Rate (g/m^2-yr)	17.76	12.76	8.52	16.20	20.65	15.29	12.01	9.97
TN Areal Loading Rate (g/m^2-yr)	110.95	142.65	82.15	118.60	142.09	143.43	143.84	146.85
TN Areal Removal Rate (gm/m^2-yr)	93.57	87.37	57.26	92.97	92.40	96.04	92.33	91.36

Table 5-1: (continued)

	Model Projection	Actual Q1+Q2+Q3 Composite	Actual Aug	Actual Sep	Actual Oct
Average Daily Flow Influent (MGD)	0.500	0.431	0.433	0.364	0.459
Average Daily Flow Effluent (MGD)	0.500	0.416	0.418	0.413	0.473
Influent TP (ppb)	560	493	421	398	428
Effluent TP (ppb)	40	79	68	104	76
Average Daily Load TP (lbs)	2.34	1.63	1.56	1.17	1.90
Influent TN (mg/l)	3.25	4.47	7.06	6.19	4.47
Effluent TN (mg/l)	0.51	1.68	1.66	2.38	2.16
Average Daily Load TN (lbs)	15.87	14.46	23.19	15.21	17.62
Average Daily Removal TP lb/day (%)	2.17 (92.7%)	1.42 (84.0%)	1.31 (83.8%)	0.83 (74.0%)	1.41 (82.3%)
Average Daily Removal TN lb/day (%)	11.43 (84.4%)	9.72 (61.3%)	17.05 (73.5%)	8.48 (55.8%)	10.70 (55.3%)
TP Areal Loading Rate (g/m^2-yr)	19.12	15.54	14.01	10.12	15.40
TP Areal Removal Rate (g/m^2-yr)	17.76	12.76	11.74	7.49	13.80
TN Areal Loading Rate (g/m^2-yr)	110.95	142.65	208.52	136.77	173.79
TN Areal Removal Rate (g/m^2-yr)	93.57	87.37	153.33	76.27	96.17

Note: Surface area for actual system 18,433 m^2 versus 20,242 m^2 for projected system

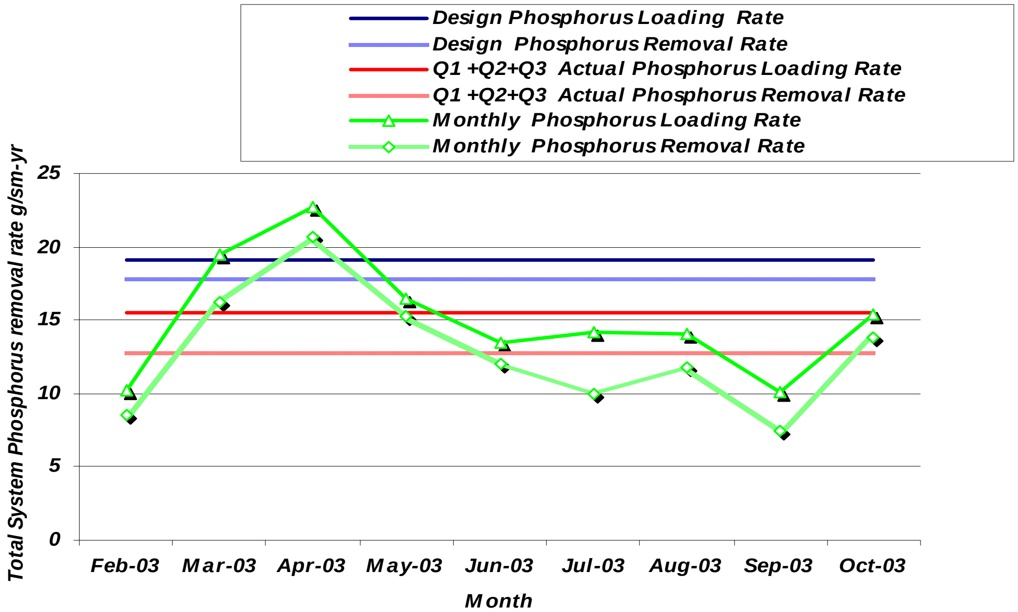


Figure 5-3: S-154 ATS™ -WHS™ actual total phosphorus loading and removal rates versus design projections Q1 through Q3

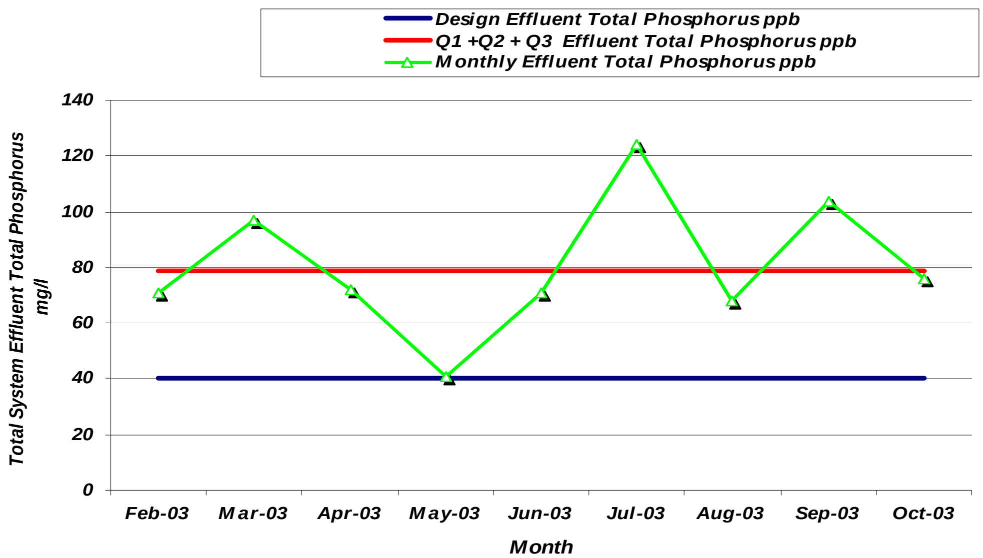


Figure 5-4: S-154 ATS™ -WHS™ actual total phosphorus effluent concentrations versus design projections Q1 through Q3.

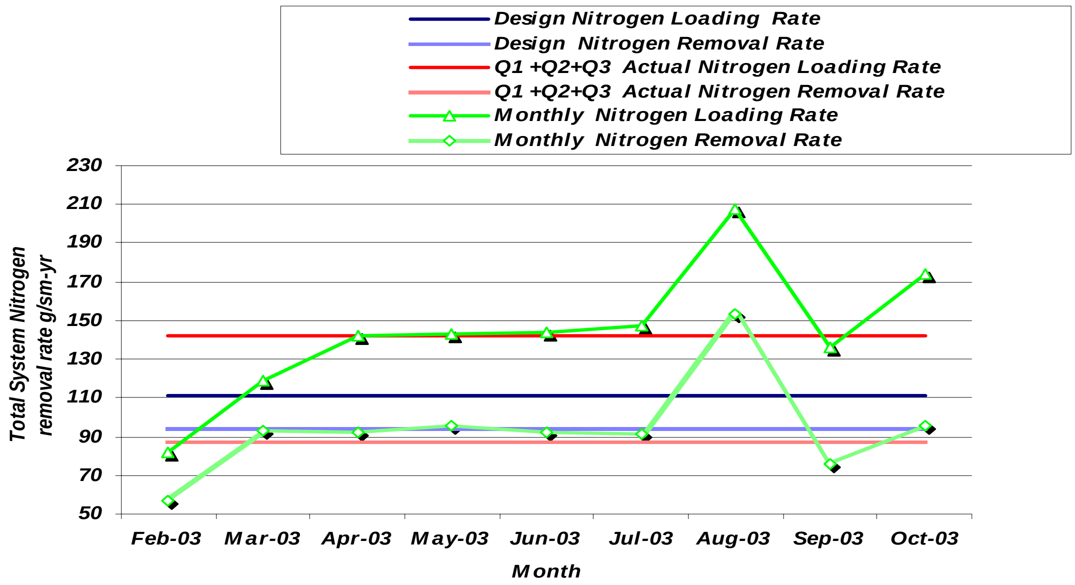


Figure 5-5: S-154 ATS™ -WHS™ actual total nitrogen loading and removal rates versus design projections Q1 through Q3.

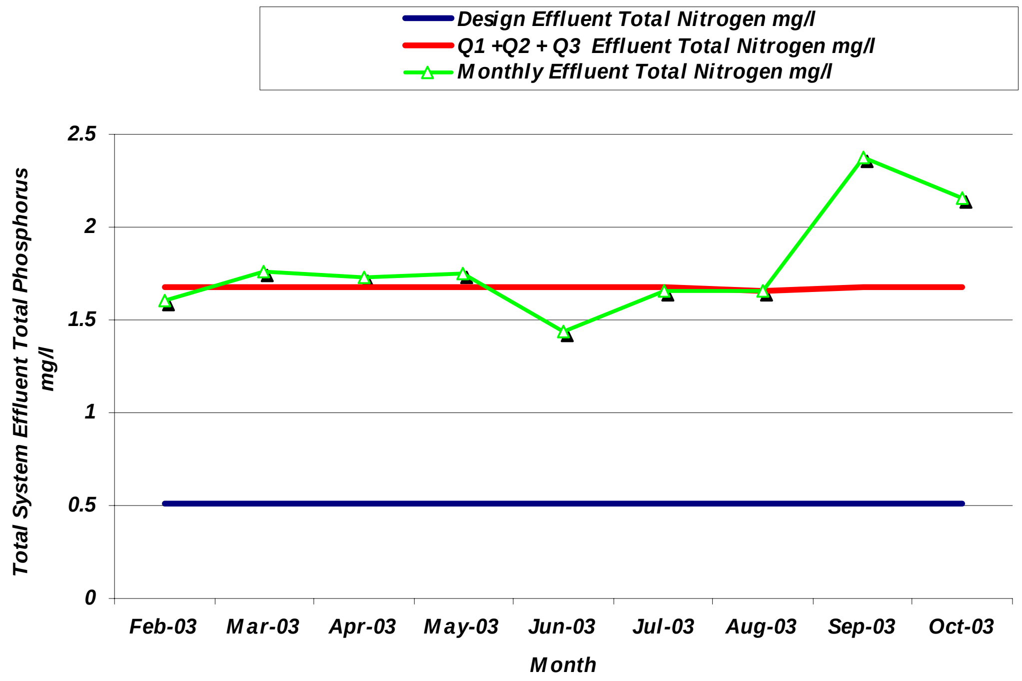


Figure 5-6: S-154 ATS™ -WHS™ actual total nitrogen effluent concentrations versus design projections Q1 through Q3.

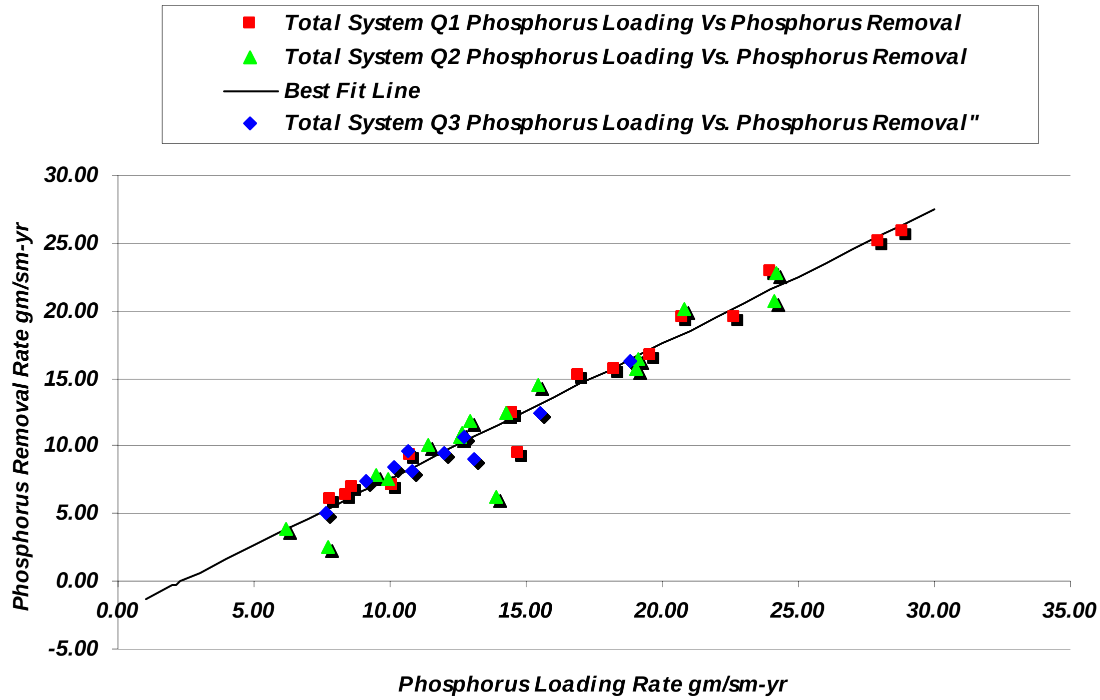


Figure 5-7: S-154 ATS™ -WHS™ phosphorus loading rate versus phosphorus removal rate Q1 through Q3.

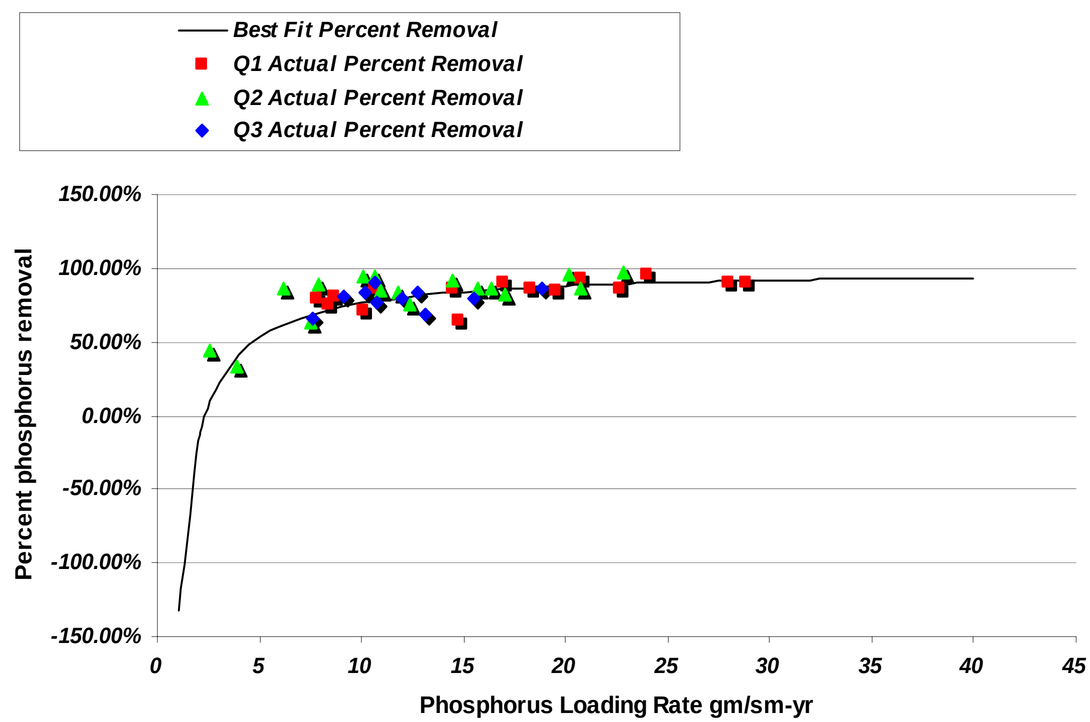


Figure 5-8: S-154 ATS™ -WHS™ phosphorus loading rate versus percent phosphorus removal Q1 through Q3.

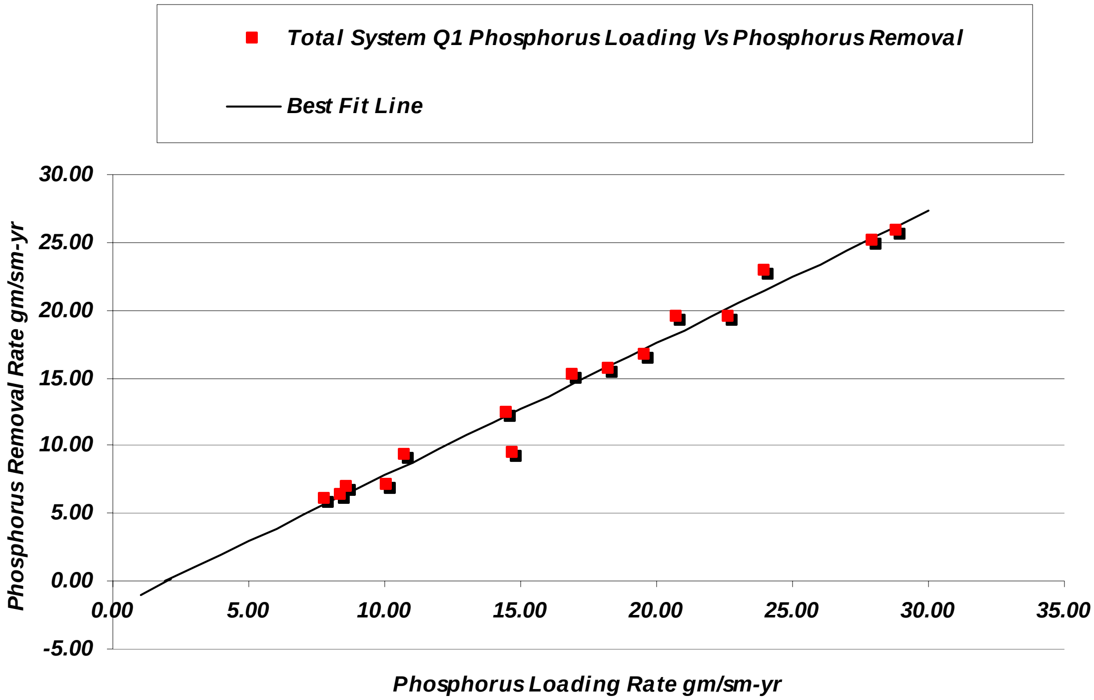


Figure 5-9: S-154 ATS™ -WHS™ phosphorus loading rate versus percent phosphorus removal for the Q1 monitoring period

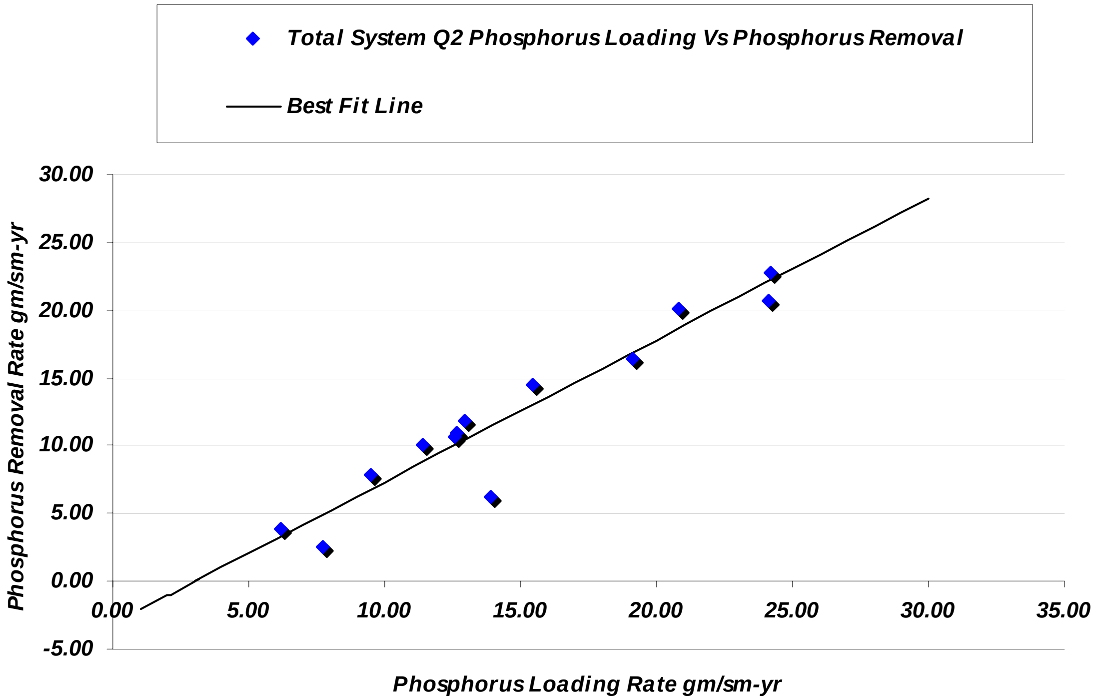


Figure 5-10: S-154 ATS™ -WHS™ phosphorus loading rate versus percent phosphorus removal for the Q2 monitoring period

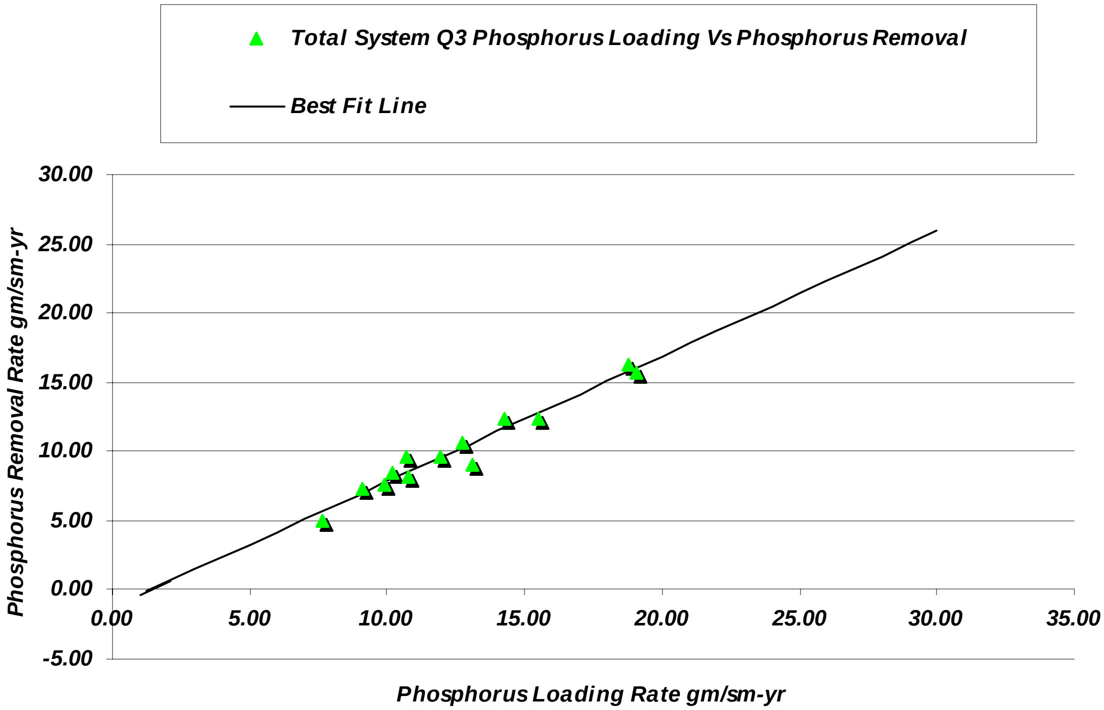


Figure 5-11: S-154 ATS™ -WHS™ phosphorus loading rate versus percent phosphorus removal for the Q3 monitoring period

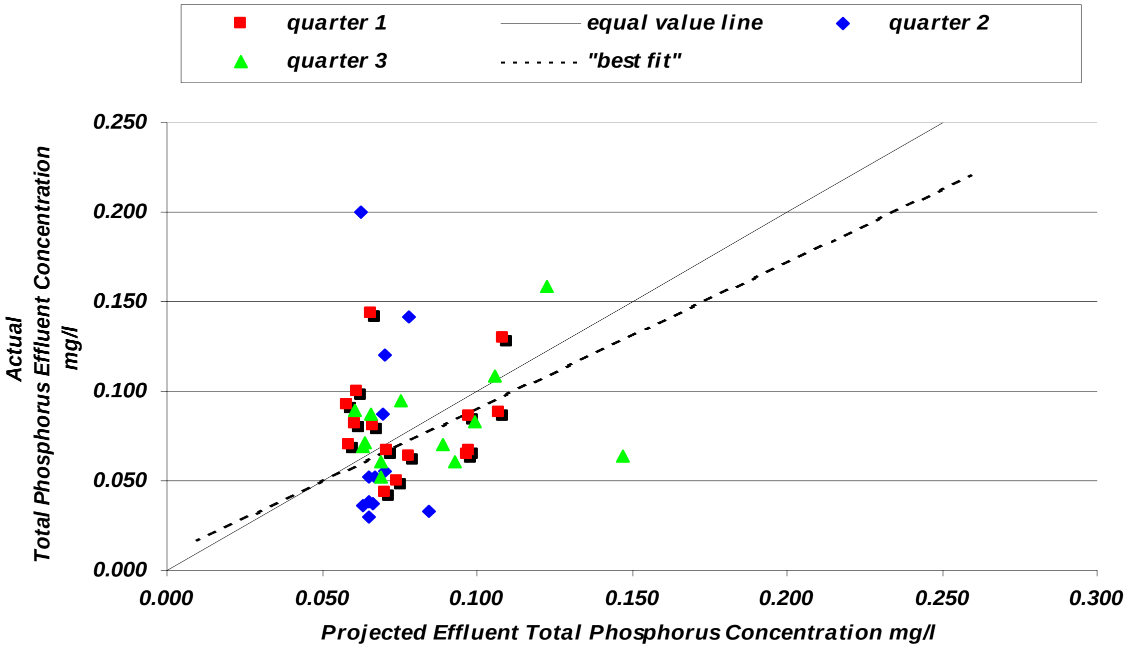


Figure 5-12: S-154 ATS™ -WHS™ projected effluent phosphorus concentrations versus actual effluent phosphorus concentrations through the Q3 monitoring period

HYADEM MODEL (WHS™)

The HYADEM model used for the WHS™ is a first order kinetics equation, as described within Appendix 14 of the Q1 Report. This model was developed in the 1980s, and has been used effectively for design and operations of full-scale hyacinth based treatment systems.

Generally the dynamic basis of performance is not dissimilar to that applied to microbial systems, such as activated sludge for domestic wastewater. However, two distinctions need to be recognized with hyacinth based MAPS technologies, these being:

- Water Hyacinths are not suspended in the water, so are not flushed out or diluted by hydraulic loads. Hence hydraulic loading, within a reasonable range with retention times greater than one day, is not as relevant in terms of biomass accumulation or growth dynamics. This is similar to some degree to fixed film type systems, which would include also the ATS™

- MAPS design involves modeling photoautotrophs rather than heterotrophs. This is important because typically the substrate targeted for removal in heterotrophic systems is usually the energy source (food) for the organism. With photoautotrophs this energy source is from captured atmospheric (or dissolved) carbon. The targeted pollutant is a subsidiary nutrient that is taken up and tissue is created as a result of photosynthesis. Therefore the model projects growth of new tissue resulting from carbon fixation, and from this the extent of nitrogen and phosphorus uptake can be estimated. This is important because the rate of accumulation of biomass per unit of nutrient uptake is considerably higher than the microbial biomass generated in the course of metabolizing organic carbon—hence harvesting and biomass management play a much greater operational role.

The operational intent is to establish a "quasi-steady state" balance between harvesting and growth. Hence, if the crop growth rate is represented as μ**,** and the daily growth is harvested every day so the standing crop is sustained at Z, then:

$$dZ/dt = \mu Z - k_d Z - h = Z(\mu - k_d) - h = 0 \quad \textbf{(Equation 9)}$$

Where **t** is time, **h** is the mass harvested, and $\mathbf{k_d}$ is the tissue sloughing rate

This relationship is similar to that used in activated sludge design in which $\mathbf{k_d}$ is designated as the endogenous respiration rate, which relates to the death of cells, and their subsequent incorporation into the metabolic regime of the remaining viable biomass. Within aquatic plant systems, the loss of tissue through normal necrosis and the resulting deposition to the sediments, while somewhat different than the concept of endogenous respiration, does represent a loss of biomass, and must be accounted for within any dynamic modeling effort.

There is also a connection between the tissue sloughing rate and the DMSTA phosphorus accretion rate S, in that much of the accreted phosphorus within a passive wetland system, such as an STA, is associated with sloughing of aquatic plant tissue. Because there is no actual harvesting and removal of aquatic plant tissue within an STA, design and performance modeling does not include a steady state growth vs. harvest component, i.e. there is no effort to optimize plant production through harvesting as a the primary management tool.

Within the WHS™ the net growth rate μ_n**,** may be seen as the sum of the rate of new growth development and the rate of tissue loss through sloughing. The rate of new growth μ**,** can be estimated through a modification of the Monod Equation:

$$\mu = d_a \mu_{max} S/(S+K_s) \qquad \textbf{(Equation 10)}$$

Where μ_{max} is the genetic maximum growth rate potential of the organism as 1/day, **S** is the concentration of the growth controlling nutrient, K_s is the half saturation constant, or the concentration of **S** where $\mu = 0.5\mu_{max}$, and d_a is a crop density adjustment factor.

Assignment of a density adjustment factor (d_a) is based upon field experience and work by Debusk and Reddy (1987) [Density requirements to maximize productivity and nutrient removal capability of water hyacinth. In: Aquatic Plants for Water Treatment and Resource Recovery edited by K.R. Reddy and W.H. Smith. Magnolia Press, Orlando, FL USA]. The general relationship found was about a 30% decline in specific growth rate from a wet density of about 3.5 wet lbs/sq. ft., (which was found to be the optimal density for maximum productivity) to 6.0 wet lbs/sq. ft. Considering this, d_a can be approximated as:

$$d_a = 1-\{[(D_{ave}- 3.5)/2.5]0.30\} \quad 3.5< D_{ave} <6.0 \qquad \textbf{(Equation 11)}$$

A net growth rate then can be identified as

$$\mu_n = [d_a\, \mu_{max} S/(S+K_s)] - k_d \qquad \textbf{(Equation 12)}$$

therefore

$$dZ/dt = \mu_n Z - h = 0 \qquad \textbf{(Equation 13)}$$

Using this relationship in the HYADEM model allows elimination of the coefficient C_p, and provides a better estimate of harvesting and sediment management needs. The value of k_d can be estimated as:

$$k_d = [(M_p - S_p)/(H_p H_w t_d)]/Z_{ave} \qquad \textbf{(Equation 14)}$$

Where M_p = Total mass of phosphorus deposited to sediments during time t_d

S_p = Mass of phosphorus deposited to sediments during time t_d which are directly attributable to influent particulate loads.

H_p, H_w = fraction dry weight phosphorus content of whole water hyacinths, and the fraction water content of whole water hyacinths, respectively

t_d = time interval in days

Z_{ave} = Average wet standing crop of water hyacinths during time t_d

At relatively high nutrient levels —TN > 1.5 mg/l and TP > 150 ppb—the HYADEM model has shown to offer reasonable estimates of growth, and accordingly, reasonable estimates of effluent water quality and harvest amounts. Over the years, adjustments have been made to the maximum growth rate, μ_{max}, because of the impacts of the hyacinth weevil. The maximum growth rate that has proven reliable has been 0.04/day. This is considerably lower than the values developed in controlled growth conditions of 0.15/day, as developed by researchers such as Musil and Breen in the seventies (Musil, C.F and C.M. Breen, 1977. "The application of growth kinetics to the control of *Eichhornia crassipes* (Mart) Solms through nutrient removal by mechanical harvesting." ***Hydrobiologia*** 53:165).

The μ_{max} = 0.04/day as used in HYADEM is more representative of a net field productivity rate, rather than a representation of the physiological capabilities of the plant itself, and it accounts to some extent for grazing losses, intra and inter-specific competition, and other environmental factors which impact growth in the field, such as wind impacts, solar intensity, mineral availabilities, sediment and organic loads, pH, DO and salinity influences, etc. It does not include specific consideration of plant density influences or of long term tissue sloughing, which, based upon experience, appears to be more of an issue in low nutrient conditions when the “mean plant age”, or MPA is comparatively high. These two factors have been incorporated in to the modified equations—Equation 9 and 10. The MPA may be viewed as the average time a plant is in the system before being removed, and is considered equal to the inverse of the specific growth rate. Therefore, at high nutrient levels, those being well above 6.50 mg/l total nitrogen (**S** is estimated at 6.50 mg/l TN), the specific growth rate can be expected to be close to μ_{max}, and the MPA accordingly would approach 25 days—for example at a total nitrogen level of 20 mg/l, which might be typical of a domestic wastewater effluent, the specific growth rate at summer temperatures would be estimated at 0.032/day, and the MPA would be about 31 days. When the total nitrogen is considerably less than 5 mg/l, which would be expected in many surface water management systems, the specific growth rate drops, and the MPA rises considerably. For example, at a total nitrogen level of 3 mg/l, the specific growth rate at summer temperatures would be estimated at 0.015 and the MPA therefore would be about 66 days.

If the rate of sloughing can be related to plant age, then it would be expected to be more of an issue with higher MPA values. This is an issue that certainly needs continued evaluation and refinement. As noted, however, sloughing of tissue and subsequent delivery to the sediments has been considered in the past as a constant loss input as a percentage of removed nutrients. For example an incidental loss coefficient ($\mathbf{C_p}$) of 0.20 means that 20 percent of the removed phosphorus is manifested in the sediments and other compartments, exclusive of harvested plant tissue. This approach can be replaced at least for phosphorus with Equation 9, in which a sloughing rate ($\mathbf{k_d}$) is considered. The incidental loss coefficient for nitrogen ($\mathbf{C_n}$) represents more than just sloughing, as denitrification is often the dominant influence in nitrogen removal. Therefore this factor is retained within the model. Stewart et al. (1987) noted $\mathbf{C_n}$ values of 0.30 to 0.60 within five full-scale WHS™ operations.

Outflow Concentration Optimization Period

The WHS™ composite specific annual average specific growth rate projection for the planned twelve-month period of operations was 0.017/day, as noted in Figure 5-1. If the HYADEM model is modified to include Equations 9and 10; a $\mathbf{C_n}$ of 0.40; a $\mathbf{k_d}$ of 0.004/day; and adjusted for the field conditions for months during the POR as listed within Table 5-2, then HYADEM model projections can be made and compared with actual findings. These projections are also noted in Table 5-2 for Q1 through Q3, and Table 5-3 for Q4 through Q6. The actual vs. projected for harvest quantity, phosphorus and nitrogen removal rates and effluent phosphorus and nitrogen concentrations are presented within Figures 5-13 through 5-31, including the actual model printouts for Q1 through Q3.

For the entire POR the model runs provides a reasonable estimate of phosphorus removals and concentrations, as noted in Figure 5-14 5-15,5-28 and 5-29. The actual versus projected total phosphorus concentrations for Q4 through Q6 and particularly close, as noted in Figure 5-29.

It is noteworthy that during Q1 through Q3, there is greater variability in the phosphorus dynamics than with nitrogen, which could be interpreted as indicative of active sediment involvement. During start-up, phosphorus projections were low in terms of removal rates, with higher than actual effluent concentration. By June, this reversed, with removal rate projections higher, and effluent concentration projections lower than actual. It is likely that during start-up sediments stores are being filled, hence the higher than expected removal rates. By summer, these deposited sediments appear to be releasing some phosphorus back to the water column, resulting in a higher than projected effluent concentration.

Load Reduction Optimization Period

During Q4 through Q6, there is noted a slightly higher actual removal rate when compared to projected removal rate when applied to phosphorus. The effluent concentration projections match very well with actual concentrations, with the exception of March and April, when the projected concentrations are notably higher than the actual concentrations. For the entire Q4 through Q6 period, the average projected total phosphorus concentration is 283 ppb, while the average actual concentration was 265 ppb. It is interesting that the performance of the WHS™ continued through the two hurricanes, although, not surprisingly, a great deal of tissue was sloughed to the sediments as a result of the two storms.

Organic material is sloughed within the WHS™ during the course of the year. This material tends to stabilize through both aerobic and anaerobic digestion. Anaerobic conditions prevail in the summer. It is likely during this decomposition that some of the accrued phosphorus is released. The composting/digestion process however, also reduces the overall sediment mass through release of carbon dioxide and gaseous nitrogen, and overall volume through consolidation. For example, if there is a 25% loss of dry weight through this process, and the sediment consolidates to 90% moisture, then for each wet ton of sloughed material at 95% moisture, 750 wet pounds of sediment accumulates on the bottom of the WHS™ unit. With an assumed density close to that of water—62.4 lbs/cf—then about 12 cf of sediment will accumulate with each ton of sloughed material, or 0.006 cf for each pound of sloughed material. When the standing crop density is 4.25 lb/ft^2, then 0.017 lb/day of material is sloughed per square foot when $\mathbf{k_d}$ = 0.004/day. This will result in approximately ½ inch per year of material. This is somewhat misleading however, because before the sediment consolidates, it needs to be compressed by overlying sediments which will be less consolidated, and hence more flocculent and labile. If these overlying sediments form a loose floc of material at 3-5% moisture, then a deeper transition layer of 1-2 inches would develop over a year's time. It is within the dynamic formation of this sediment layer that the complex transformation of phosphorus likely occurs, not dissimilar to the phenomenon described by Williams, J.D.H. and T. Meyer (1972) ["Effects of sediment diagenesis and regeneration of phosphorus with special reference to Lakes Erie and Ontario." In J.R. Kramer and H.E. Allen (Ed) Nutrients in Natural Waters pp. 281-315. John Wiley and Sons. NY] in their work related to phosphorus dynamics in lake sediments.

Nitrogen dynamics during Q1 through Q3, as noted in Figures 5-16 and 5-17, show far less variability than noted during Q4 through Q6 as seen in Figures 5-30 and 5-31, and the projections accordingly are somewhat closer to actual values during the Q1 through Q3 period. These trends are indicative of the role of denitrification in nitrogen removal within WHS™ facilities. While a $\mathbf{C_n}$ of 0.40 is used during the modeling, as discussed previously, during Q4 through Q6 the actual $\mathbf{C_n}$ was calculated as 0.60, resulting in higher removal rates than projected. The high rate of denitrification may well be associated with an attendant high rate of nitrification, which appears to be prevalent during this period. It has long been recognized that nitrification can occur within the root zone of a healthy hyacinth crop, and that actual active transport of oxygen to the root zone to facilitate can help facilitate nitrification. Denitrification therefore would occur within an active benthic zone in which micro-aerophilic conditions would encourage certain facultative bacteria to utilize the nitrate as an electron source, resulting in release of nitrogen to the atmosphere. When nitrogen is the targeted pollutant, it is obviously advantageous to maximize $\mathbf{C_n}$ through the promotion of nitrification-denitrification.

Growth dynamics during Q1 through Q3 and Q4 through Q6 indicate that the model can at times, under-estimate the harvesting needs, as shown in Figure 5- 13 and 5-26. However, as noted in Figure 5-26, the projected growth rate closely tracks the actual harvest rates, and it is suggested that for designing a harvesting plan, the projected growth rate should be considered as the basis of maximum harvest demand. The growth rate, as mentioned previously, represents the sum of the new tissue and the sloughed tissue. As sloughing involves potential regeneration of nutrients into the water column, there is always a possibility that additional production could be stimulated. This possibility of recycling requires the engineer to design maximum harvesting capacity around the higher growth numbers, while also being prepared to include provisions for active removal of the deposited sediments. There is of course as trade-off involved here. If the net growth is higher than projected, then the sediment removal demands will be diminished, Reciprocally, if the net growth rate is lower than projected, then the sediment rate will be higher, and greater effort will be required for sediment management.

Table 5-2: Field conditions and projections for modified HYADEM model for the period January 27, 2003 through November 3, 2003 (Q1 through Q3).

	February	March	April	May	June	July	August	September	October
Average Air T (^{o}C)	18.8	22.5	22.1	25.1	26.2	26.7	26.4	26.0	24.0
Initial Standing Crop wet tons	93	128	199	172	151	228	167	201	203
End Standing Crop wet tons	128	199	172	151	228	167	201	203	201
Average Standing Crop wet tons	111	179	179	187	182	195	173	200	211
Average Crop Density lb/sq.ft.	3.55	3.49	4.24	4.85	6.00	5.30	4.92	5.55	5.55
Density Adjustment Factor d_a	1.00	1.00	0.96	0.87	0.60	0.71	0.77	0.67	0.67
Incidental Nitrogen Loss C_n	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Average Influent TN mg/l	2.40	2.56	2.99	3.06	2.73	3.07	5.19	4.34	3.33
Average Influent TP mg/l	375	515	653	572	375	432	504	474	397
Tissue P Content (% dw)	0.29	0.36	0.45	0.45	0.45	0.49	0.51	0.48	0.46
Tissue N Content (% dw)	2.40	2.45	2.40	2.61	2.35	2.22	2.50	2.26	2.13
Projected total phosphorus WHS ™ effluent concentration ppb	**291**	**356**	**426**	**312**	**213**	**162**	**258**	**194**	**145**
Actual total phosphorus WHS ™ effluent concentration ppb	***97***	***168***	***120***	***136***	***203***	***312***	***223***	***225***	***200***
Projected total phosphorus WHS ™ removal rate g/m^2-yr	**3.83**	**10.63**	**13.98**	**15.60**	**10.61**	**16.25**	**14.44**	**13.78**	**15.82**
Actual total phosphorus WHS ™ removal rate g/m^2-yr	***13.95***	***25.55***	***33.40***	***24.99***	***11.73***	***7.23***	***12.52***	***9.15***	***11.12***
Projected total nitrogen WHS ™ effluent concentration ppb	**1.98**	**1.87**	**2.56**	**2.26**	**2.58**	**2.59**	**1.64**	**2.41**	**2.93**
Actual Total nitrogen WHS™ effluent concentration ppb	***1.68***	***2.40***	***1.77***	***1.51***	***1.59***	***1.62***	***1.70***	***2.44***	***2.35***
Projected Total nitrogen WHS™ removal rate g/m^2-yr	**49**	**101**	**104**	**127**	**94**	**111**	**99**	**95**	**103**
Actual Total nitrogen WHS™ removal rate g/m^2-yr	***65***	***86***	***127***	***138***	***130***	***130***	***134***	***106***	***112***
Projected Specific Growth Rate (1/day)	**0.008**	**0.010**	**0.011**	**0.011**	**0.009**	**0.011**	**0.010**	**0.009**	**0.010**
Actual Specific Growth Rate (1/day)	***0.021***	***0.022***	***0.016***	***0.025***	***0.016***	***0.009***	***0.025***	***0.010***	***0.010***
Projected Net Growth Rate (1/day	**0.004**	**0.006**	**0.007**	**0.007**	**0.005**	**0.007**	**0.006**	**0.005**	**0.006**
Actual Net Growth Rate (1/day)	***0.012***	***0.018***	***0.013***	***0.016***	***0.007***	***0.001***	***0.020***	***0.006***	***0.006***
Projected Sloughing Growth Rate (1/day)	**0.004**	**0.004**	**0.004**	**0.004**	**0.004**	**0.004**	**0.004**	**0.004**	**0.004**
Actual Sloughing Rate (1/day)	***0.009***	***0.004***	***0.003***	***0.009***	***0.009***	***0.008***	***0.005***	***0.004***	***0.004***
Projected Weekly Harvest (wet tons)	**2.8**	**7.0**	**5.6**	**8.4**	**3.5**	**6.3**	**6.3**	**3.5**	**8.4**
Actual Weekly Harvest (wet tons)	***No harvest***	***7.2***	***9.5***	***11.1***	***5.3***	***9.3***	***5.4***	***6.9***	***8.2***

Table 5-3: Field conditions and projections for modified HYADEM model for the period November 4, 2003 through October 18, 2004 (Q4 through Q6).

	November	December	Jan 2004	Feb 2004	March 2004	April 2004	May 2004	June 204	July 2004
Average Air T (^oC)	19.4	15.4	15.2	17.7	19.3	20.4	24.1	26.2	26.7
Initial Standing Crop wet tons	112	107	95	99	91	122	112	139	131
End Standing Crop wet tons	107	95	99	91	122	112	139	131	126
Average Standing Crop wet tons	107	94	94	90	104	111	130	140	126
Average Crop Density lb/sq.ft.	5.74	5.50	4.71	4.31	4.15	4.10	4.91	4.85	4.90
Density Adjustment Factor d_a	0.73	0.76	0.85	0.90	0.92	0.93	0.83	0.84	0.83
Incidental Nitrogen Loss C_n	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Average Influent TN mg/l	6.14	4.18	2.85	1.67	1.89	2.40	2.69	3.29	2.46
Average Influent TP mg/l	0.226	0.119	0.136	0.132	0.457	0.280	0.235	0.164	0.089
Tissue P Content (% dw)	0.48	0.39	0.35	0.24	0.30	0.39	0.39	0.31	0.18
Tissue N Content (% dw)	2.43	2.62	2.76	2.56	1.82	2.13	2.23	2.05	2.99
Projected total phosphorus WHS ™ effluent concentration ppb	**152**	**80**	**107**	**118**	**431**	**230**	**172**	**92**	**58**
Actual total phosphorus WHS ™ effluent concentration ppb	***165***	***88***	***101***	***107***	***263***	***160***	***106***	***54***	***50***
Projected total phosphorus WHS ™ removal rate g/m^2-yr	**18.11**	**8.63**	**5.54**	**2.85**	**6.20**	**13.96**	**16.10**	**17.34**	**7.40**
Actual total phosphorus WHS ™ removal rate g/m^2-yr	***15.37***	***6.81***	***7.11***	***5.48***	***45.37***	***28.25***	***30.74***	***26.02***	***9.15***
Projected total nitrogen WHS ™ effluent concentration ppb	**5.55**	**3.82**	**2.53**	**1.46**	**1.67**	**2.02**	**2.19**	**2.95**	**1.73**
Actual Total nitrogen WHS™ effluent concentration ppb	***2.70***	***1.87***	***2.24***	***1.54***	***1.32***	***1.13***	***1.04***	***1.09***	***1.09***
Projected Total nitrogen WHS™ removal rate g/m^2-yr	**204**	**72**	**47**	**44**	**53**	**110**	**136**	**96**	**176**
Actual Total nitrogen WHS™ removal rate g/m^2-yr	***775***	***519***	***132***	***19***	***131***	***291***	***396***	***522***	***331***
Projected Specific Growth Rate (1/day)	**0.0110**	**0.0070**	**0.0060**	**0.0050**	**0.0060**	**0.0080**	**0.0090**	**0.0120**	**0.009**
Actual Specific Growth Rate (1/day)	***0.0096***	***0.0068***	***0.0147***	***0.0076***	***0.0195***	***0.0115***	***0.0186***	***0.0149***	***0.0087***
Projected Net Growth Rate (1/day	**0.0070**								
Actual Net Growth Rate (1/day)	***0.0058***	***0.0026***	***0.0105***	***0.0047***	***0.0169***	***0.0090***	***0.0166***	***0.0109***	***0.0048***
Projected Sloughing Growth Rate (1/day)	**0.0040**	**0.0040**	**0.0040**	**0.0040**	**0.0040**	**0.0040**	**0.0040**	**0.0040**	**0.0040**
Actual Sloughing Rate (1/day)	***0.0038***	***0.0042***	***0.0042***	***0.0029***	***0.0026***	***0.0025***	***0.0020***	***0.0040***	***0.0039***
Projected Weekly Harvest (wet tons)	**4.9**	**2.1**	**1.4**	**0.7**	**1.4**	**2.8**	**4.2**	**7.7**	**4.2**
Projected Weekly growth (wet tons)	***8.4***	***5.6***	***4.2***	***2.8***	***4.2***	***5.6***	***8.4***	***11.9***	***7.7***
Actual Weekly Harvest (wet tons)	***5.4***	***4.7***	***6.4***	***4.7***	***5.1***	***9.8***	***8.4***	***12.4***	***9.3***

Table 5-3: Continued

	August 2004	September 2004	October 2004
Average Air T (^oC)	27.7	27.7	24.2
Initial Standing Crop wet tons	126	113	112
End Standing Crop wet tons	113	112	105
Average Standing Crop wet tons	105	129	108
Average Crop Density lb/sq.ft.	5.65	5.82	5.18
Density Adjustment Factor d_a	0.74	0.72	0.80
Incidental Nitrogen Loss C_n	0.40	0.40	0.40
Average Influent TN mg/l	2.62	3.05	2.96
Average Influent TP mg/l	0.302	0.728	0.987
Tissue P Content (% dw)	0.21	0.42	0.42*
Tissue N Content (% dw)	1.70	2.40	2.42*
Projected total phosphorus WHS ™ effluent concentration ppb	**266**	**765**	**1,021**
Actual total phosphorus WHS ™ effluent concentration ppb	***277***	***810***	***1,000***
Projected total phosphorus WHS ™ removal rate g/m^2-yr	**8.26**	**18.05**	**17.09**
Actual total phosphorus WHS ™ removal rate g/m^2-yr	***16.47***	***15.92***	***21.16***
Projected total nitrogen WHS ™ effluent concentration ppb	**2.23**	**1.98**	**2.53**
Actual Total nitrogen WHS™ effluent concentration ppb	***1.45***	***1.80***	***1.60***
Projected Total nitrogen WHS™ removal rate g/m^2-yr	**89**	**144**	**122**
Actual Total nitrogen WHS™ removal rate g/m^2-yr	***230***	***174***	***330***
Projected Specific Growth Rate (1/day)	**0.0090**	**0.0090**	**0.0090**
Actual Specific Growth Rate (1/day)	***0.0064***	***0.0262***	***0.0214***
Projected Net Growth Rate (1/day	**0.0076**	**0.0050**	**0.0050**
Actual Net Growth Rate (1/day)	***0.0025***	***-0.0003***	***0.0074***
Projected Sloughing Growth Rate (1/day)	**0.0040**	**0.0040**	**0.0040**
Actual Sloughing Rate (1/day)	***0.0039***	***0.0265***	***0.0140***
Projected Weekly Harvest (wet tons)	**4.8**	**4.2**	**3.5**
Projected Weekly growth (wet tons)	***7.0***	***7.7***	***7.0***
Actual Weekly Harvest (wet tons)	***4.8***	***No harvest***	***9.0***

*No samples for October. September values used.

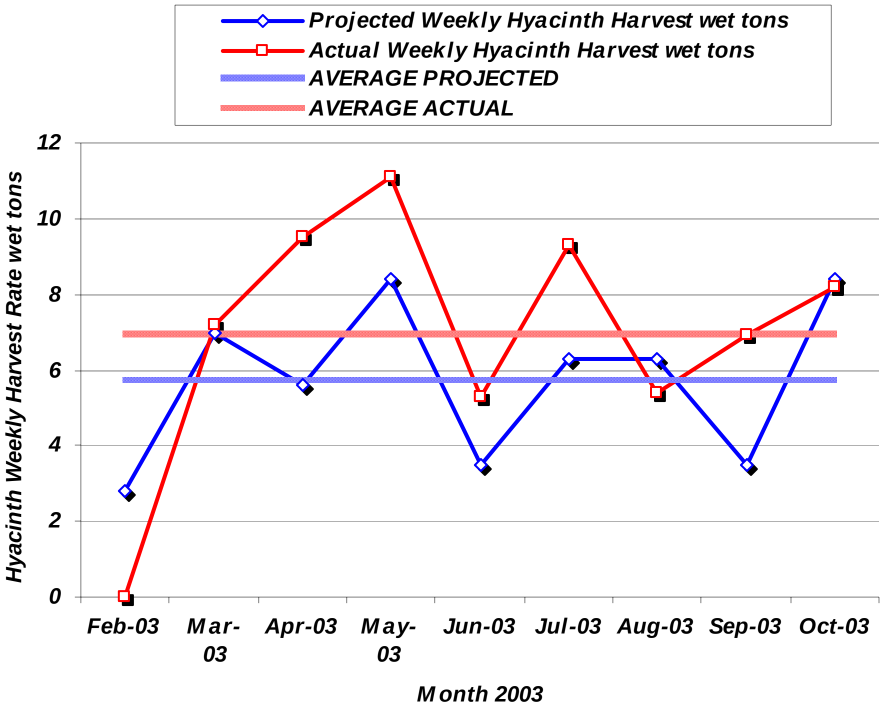


Figure 5-13: S-154 WHS™ actual weekly hyacinth harvest rates versus HYADEM model projections for weekly harvest rates by month through the Q3 monitoring period.

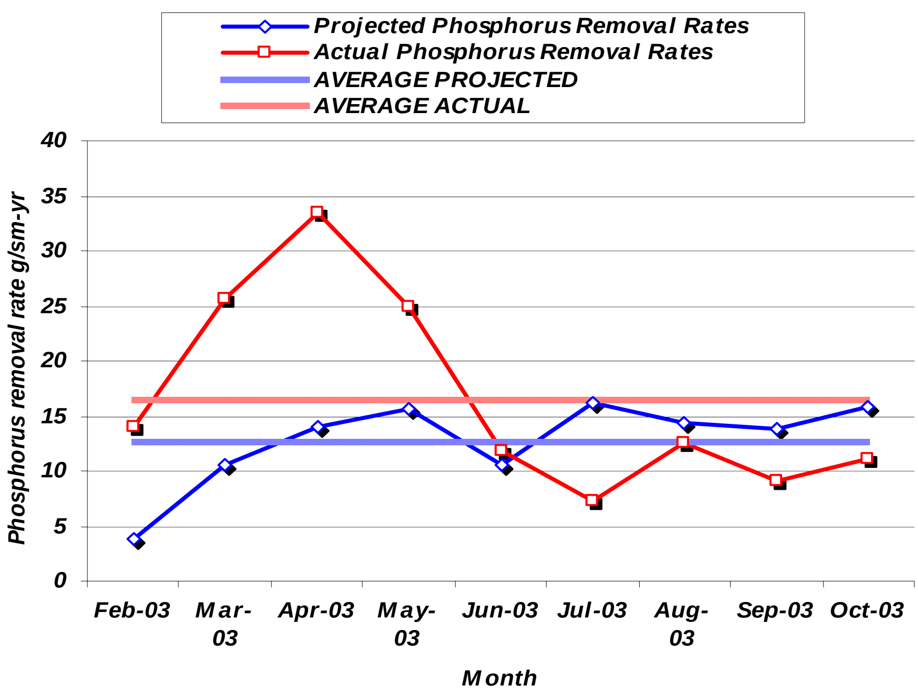


Figure 5-14: S-154 WHS™ actual total phosphorus areal removal rates versus HYDEM model projections for areal removal rates by month through the Q3 monitoring period

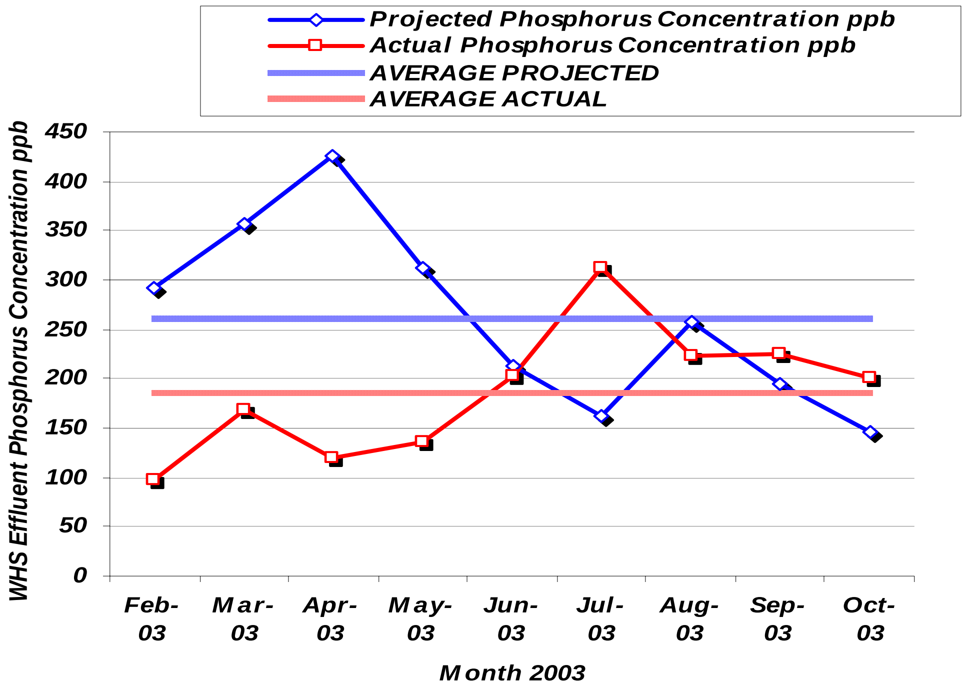


Figure 5-15: S-154 WHS™ actual total phosphorus effluent concentration versus HYDEM model projections for effluent total phosphorus concentration by month through the Q3 monitoring period

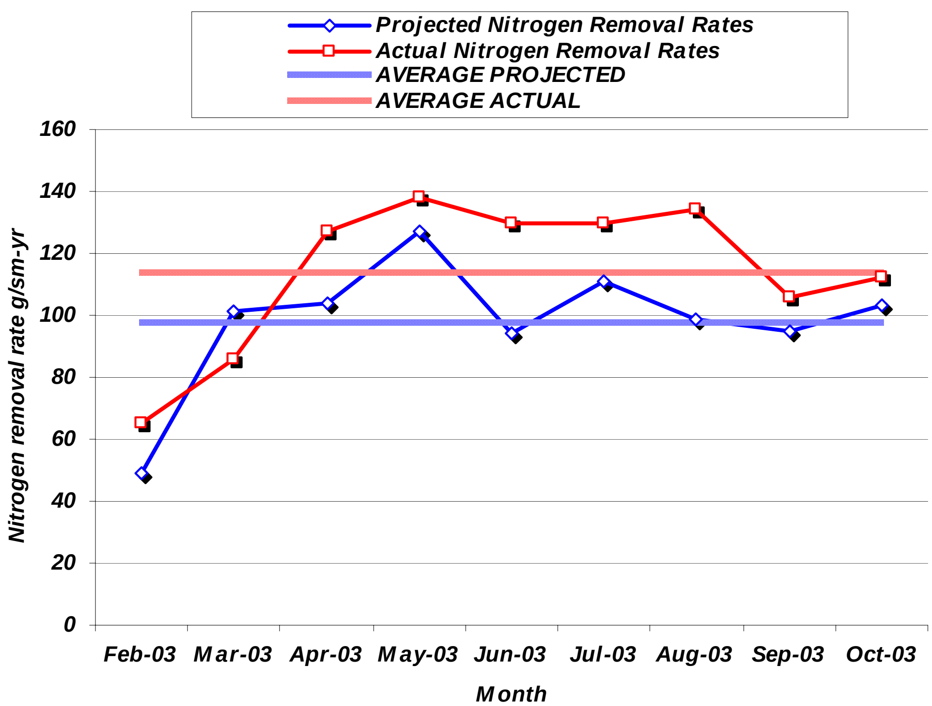


Figure 5-16: S-154 WHS™ actual total nitrogen areal removal rates versus HYDEM model projections for areal removal rated by month through the Q3 monitoring period

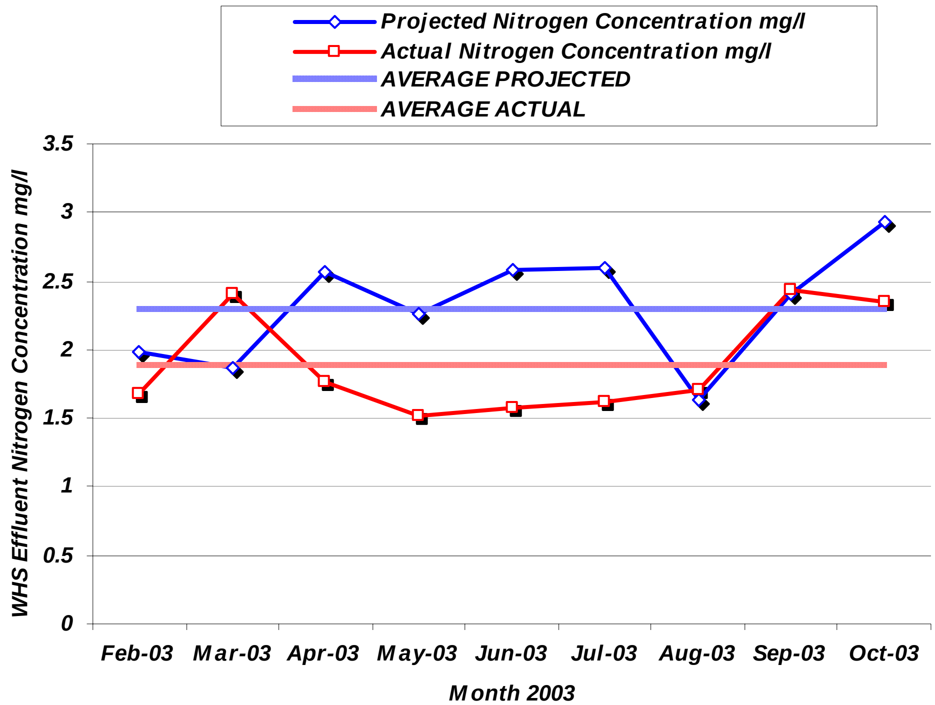


Figure 5-17: S-154 WHS™ actual total nitrogen effluent concentration versus HYADEM model projections of effluent concentration through the Q3 monitoring period

HYADEM February 2003

INPUTS	
Influent Average Daily Flow (mgd)	0.34
Effluent Average Daily Flow (mgd)	0.33
Average Total Nitrogen (mg/l)	2.40
Influent Total Nitrogen (mg/l)	3.04
Influent Total Phosphorus (mg/l)	0.37
V'ant Hoff Arrhenius Coefficient	1.05
Average Air Temperature (degrees C)	18.80
Maximium Specific Growth Rate (1/day)	0.040
Wet Crop Density (lb/sf)	3.55
Density Adjustment Factor	1.00
Half Rate Concentration (mg/l TN)	6.50
Incidental Nitrogen Loss C_n	0.40
Growing Area (acres)	2.50
Percent Coverage	57.60%
Plant Nitrogen Content (% dry weight)	2.40%
Plant Phosphorus Content (% dry weight)	0.29%
Percent Solids Harvest	5.90%
In-Pond Plant percent solids	5.00%
OUTPUTS	
Standing Crop (Wet Tons)	111
Field Water Hyacinth Growth Rate (1/day)	0.008
Sloughing Rate (1/day)	0.004
Net Specific Growth Rate (1/day)	0.004
Average Pond Depth (ft)	3.50
Hydraulic retention time (days)	8.39
Average Daily Growth (Wet Tons)	0.9
Average Daily Harvest (Wet Tons)	0.4
Average Daily Sloughing (Wet Tons)	0.4
WHS™ Effluent Total Nitrogen (mg/l)	**1.98**
WHS™ Effluent Total Phosphorus (mg/l)	**0.291**
Nitrogen Removal lb/day	2.99
Nitrogen Removal ton/yr	0.55
Nitrogen Removal Rate lb/acre-day	1.20
Nitrogen Removal Rate gm/sm-yr	49.02
Phosphorus Removal lb/day	0.23
Phosphorus Removal ton/yr	0.04
Phosphorus Removal Rate lb/acre-day	0.09
Phosphorus Removal Rate gm/sm-yr	3.83

Figure 5-18: HYADEM model run for February 2003

HYADEM March 2003

INPUTS	
Influent Average Daily Flow (mgd)	0.49
Effluent Average Daily Flow (mgd)	0.48
Average Total Nitrogen (mg/l)	2.56
Influent Total Nitrogen (mg/l)	3.38
Influent Total Phosphorus (mg/l)	0.52
V'ant Hoff Arrhenius Coefficient	1.05
Average Air Temperature (degrees C)	22.50
Maximium Specific Growth Rate (1/day)	0.040
Density Adjustment Factor	1.00
Wet Crop Density (lb/sf)	3.49
Half Rate Concentration (mg/l TN)	6.50
Incidental Nitrogen Loss C_n	0.40
Growing Area (acres)	2.50
Percent Coverage	94.40%
Plant Nitrogen Content (% dry weight)	2.45%
Plant Phosphorus Content (% dry weight)	0.36%
Percent Solids Harvest	5.20%
Plant percent solids	5.00%
OUTPUTS	
Standing Crop (Wet Tons)	179
Field Water Hyacinth Growth Rate (1/day)	0.010
Sloughing Rate (1/day)	0.004
Net Specific Growth Rate (1/day)	0.006
Average Pond Depth (ft)	3.50
Hydraulic retention time (days)	5.82
Average Daily Growth (Wet Tons)	1.8
Average Daily Harvest (Wet Tons)	1.0
Average Daily Sloughing (Wet Tons)	0.7
WHS™ Effluent Total Nitrogen (mg/l)	**1.87**
WHS™ Effluent Total Phosphorus (mg/l)	**0.356**
Nitrogen Removal lb/day	6.19
Nitrogen Removal ton/yr	1.13
Nitrogen Removal Rate lb/acre-day	2.47
Nitrogen Removal Rate gm/sm-yr	101.30
Phosphorus Removal lb/day	0.65
Phosphorus Removal ton/yr	0.12
Phosphorus Removal Rate lb/acre-day	0.26
Phosphorus Removal Rate gm/sm-yr	10.63

Figure 5-19: HYADEM model run for March 2003

HYADEM April 2003

INPUTS	
Influent Average Daily Flow (mgd)	0.45
Effluent Average Daily Flow (mgd)	0.42
Average Total Nitrogen (mg/l)	2.99
Influent Total Nitrogen (mg/l)	4.26
Influent Total Phosphorus (mg/l)	0.65
V'ant Hoff Arrhenius Coefficient	1.05
Average Air Temperature (degrees C)	22.10
Maximium Specific Growth Rate (1/day)	0.040
Wet Crop Density (lb/sf)	4.24
Density Adjustment Factor	0.96
Half Rate Concentration (mg/l TN)	6.50
Incidental Nitrogen Loss C_n	0.40
Growing Area (acres)	2.50
Percent Coverage	77.50%
Plant Nitrogen Content (% dry weight)	2.40%
Plant Phosphorus Content (% dry weight)	0.45%
Percent Solids Harvest	6.70%
Plant percent solids	5.00%
OUTPUTS	
Standing Crop (Wet Tons)	179
Field Water Hyacinth Growth Rate (1/day)	0.011
Sloughing Rate (1/day)	0.004
Net Specific Growth Rate (1/day)	0.007
Average Pond Depth (ft)	3.50
Hydraulic retention time (days)	6.34
Average Daily Growth (Wet Tons)	1.9
Average Daily Harvest (Wet Tons)	0.9
Average Daily Sloughing (Wet Tons)	0.7
WHS™ Effluent Total Nitrogen (mg/l)	**2.56**
WHS™ Effluent Total Phosphorus (mg/l)	**0.426**
Nitrogen Removal lb/day	6.37
Nitrogen Removal ton/yr	1.16
Nitrogen Removal Rate lb/acre-day	2.55
Nitrogen Removal Rate gm/sm-yr	104.36
Phosphorus Removal lb/day	0.85
Phosphorus Removal ton/yr	0.16
Phosphorus Removal Rate lb/acre-day	0.34
Phosphorus Removal Rate gm/sm-yr	13.98

Figure 5-20: HYADEM model run for April 2003

HYADEM May 2003

INPUTS	
Influent Average Daily Flow (mgd)	0.44
Effluent Average Daily Flow (mgd)	0.42
Average Total Nitrogen (mg/l)	3.06
Influent Total Nitrogen (mg/l)	4.37
Influent Total Phosphorus (mg/l)	0.57
V'ant Hoff Arrhenius Coefficient	1.05
Average Air Temperature (degrees C)	25.10
Maximium Specific Growth Rate (1/day)	0.040
Wet Crop Density (lb/sf)	4.85
Density Adjustment Factor	0.87
Half Rate Concentration (mg/l TN)	6.50
Incidental Nitrogen Loss C_n	0.40
Growing Area (acres)	2.50
Percent Coverage	71.00%
Plant Nitrogen Content (% dry weight)	2.61%
Plant Phosphorus Content (% dry weight)	0.45%
Percent Solids Harvest	5.90%
Plant percent solids	5.00%
OUTPUTS	
Standing Crop (Wet Tons)	187
Field Water Hyacinth Growth Rate (1/day)	0.011
Sloughing Rate (1/day)	0.004
Net Specific Growth Rate (1/day)	0.007
Average Pond Depth (ft)	3.50
Hydraulic retention time (days)	6.48
Average Daily Growth (Wet Tons)	2.1
Average Daily Harvest (Wet Tons)	1.2
Average Daily Sloughing (Wet Tons)	0.8
WHS™ Effluent Total Nitrogen (mg/l)	**2.26**
WHS™ Effluent Total Phosphorus (mg/l)	**0.312**
Nitrogen Removal lb/day	7.73
Nitrogen Removal ton/yr	1.41
Nitrogen Removal Rate lb/acre-day	3.09
Nitrogen Removal Rate gm/sm-yr	126.63
Phosphorus Removal lb/day	0.95
Phosphorus Removal ton/yr	0.17
Phosphorus Removal Rate lb/acre-day	0.38
Phosphorus Removal Rate gm/sm-yr	15.60

Figure 5-21: HYADEM model run for May 2003

HYADEM June 2003

INPUTS	
Influent Average Daily Flow (mgd)	0.48
Effluent Average Daily Flow (mgd)	0.44
Average Total Nitrogen (mg/l)	2.73
Influent Total Nitrogen (mg/l)	4.01
Influent Total Phosphorus (mg/l)	0.38
V'ant Hoff Arrhenius Coefficient	1.05
Average Air Temperature (degrees C)	26.20
Maximium Specific Growth Rate (1/day)	0.040
Wet Crop Density (lb/sf)	6.01
Density Adjustment Factor	0.70
Half Rate Concentration (mg/l TN)	6.50
Incidental Nitrogen Loss C_n	0.40
Growing Area (acres)	2.50
Percent Coverage	55.50%
Plant Nitrogen Content (% dry weight)	2.35%
Plant Phosphorus Content (% dry weight)	0.45%
Percent Solids Harvest	9.10%
Plant percent solids	5.00%
OUTPUTS	
Standing Crop (Wet Tons)	182
Field Water Hyacinth Growth Rate (1/day)	0.009
Sloughing Rate (1/day)	0.004
Net Specific Growth Rate (1/day)	0.005
Average Pond Depth (ft)	3.50
Hydraulic retention time (days)	5.94
Average Daily Growth (Wet Tons)	1.6
Average Daily Harvest (Wet Tons)	0.5
Average Daily Sloughing (Wet Tons)	0.7
WHS™ Effluent Total Nitrogen (mg/l)	**2.58**
WHS™ Effluent Total Phosphorus (mg/l)	**0.213**
Nitrogen Removal lb/day	5.74
Nitrogen Removal ton/yr	1.05
Nitrogen Removal Rate lb/acre-day	2.29
Nitrogen Removal Rate gm/sm-yr	93.93
Phosphorus Removal lb/day	0.65
Phosphorus Removal ton/yr	0.12
Phosphorus Removal Rate lb/acre-day	0.26
Phosphorus Removal Rate gm/sm-yr	10.61

Figure 5-22: HYADEM model run for June 2003

HYADEM July 2003

INPUTS	
Influent Average Daily Flow (mgd)	0.44
Effluent Average Daily Flow (mgd)	0.45
Average Total Nitrogen (mg/l)	3.07
Influent Total Nitrogen (mg/l)	4.44
Influent Total Phosphorus (mg/l)	0.43
V'ant Hoff Arrhenius Coefficient	1.05
Average Air Temperature (degrees C)	26.70
Maximium Specific Growth Rate (1/day)	0.040
Wet Crop Density (lb/sf)	5.30
Density Adjustment Factor	0.81
Half Rate Concentration (mg/l TN)	6.50
Incidental Nitrogen Loss C_n	0.40
Growing Area (acres)	2.50
Percent Coverage	67.70%
Plant Nitrogen Content (% dry weight)	2.20%
Plant Phosphorus Content (% dry weight)	0.45%
Percent Solids Harvest	8.20%
Plant percent solids	5.00%
OUTPUTS	
Standing Crop (Wet Tons)	195
Field Water Hyacinth Growth Rate (1/day)	0.011
Sloughing Rate (1/day)	0.004
Net Specific Growth Rate (1/day)	0.007
Average Pond Depth (ft)	3.50
Hydraulic retention time (days)	6.48
Average Daily Growth (Wet Tons)	2.2
Average Daily Harvest (Wet Tons)	0.9
Average Daily Sloughing (Wet Tons)	0.8
WHS™ Effluent Total Nitrogen (mg/l)	**2.59**
WHS™ Effluent Total Phosphorus (mg/l)	**0.162**
Nitrogen Removal lb/day	6.79
Nitrogen Removal ton/yr	1.24
Nitrogen Removal Rate lb/acre-day	2.72
Nitrogen Removal Rate gm/sm-yr	111.20
Phosphorus Removal lb/day	0.99
Phosphorus Removal ton/yr	0.18
Phosphorus Removal Rate lb/acre-day	0.40
Phosphorus Removal Rate gm/sm-yr	16.25

Figure 5-23: HYADEM model run for July 2003

HYADEM August 2003

INPUTS	
Influent Average Daily Flow (mgd)	0.43
Effluent Average Daily Flow (mgd)	0.45
Average Total Nitrogen (mg/l)	2.40
Influent Total Nitrogen (mg/l)	3.33
Influent Total Phosphorus (mg/l)	0.50
V'ant Hoff Arrhenius Coefficient	1.05
Average Air Temperature (degrees C)	26.40
Maximium Specific Growth Rate (1/day)	0.040
Wet Crop Density (lb/sf)	4.92
Density Adjustment Factor	0.86
Half Rate Concentration (mg/l TN)	6.50
Incidental Nitrogen Loss C_n	0.40
Growing Area (acres)	2.50
Percent Coverage	64.50%
Plant Nitrogen Content (% dry weight)	2.50%
Plant Phosphorus Content (% dry weight)	0.51%
Percent Solids Harvest	7.70%
Plant percent solids	5.00%
OUTPUTS	
Standing Crop (Wet Tons)	173
Field Water Hyacinth Growth Rate (1/day)	0.010
Sloughing Rate (1/day)	0.004
Net Specific Growth Rate (1/day)	0.006
Average Pond Depth (ft)	3.50
Hydraulic retention time (days)	6.63
Average Daily Growth (Wet Tons)	1.7
Average Daily Harvest (Wet Tons)	0.7
Average Daily Sloughing (Wet Tons)	0.7
WHS™ Effluent Total Nitrogen (mg/l)	**1.64**
WHS™ Effluent Total Phosphorus (mg/l)	**0.258**
Nitrogen Removal lb/day	6.05
Nitrogen Removal ton/yr	1.10
Nitrogen Removal Rate lb/acre-day	2.42
Nitrogen Removal Rate gm/sm-yr	99.07
Phosphorus Removal lb/day	0.88
Phosphorus Removal ton/yr	0.16
Phosphorus Removal Rate lb/acre-day	0.35
Phosphorus Removal Rate gm/sm-yr	14.44

Figure 5-24: HYADEM model run for August 2003

HYADEM September 2003

INPUTS	
Influent Average Daily Flow (mgd)	0.36
Effluent Average Daily Flow (mgd)	0.37
Average Total Nitrogen (mg/l)	2.54
Influent Total Nitrogen (mg/l)	4.34
Influent Total Phosphorus (mg/l)	0.47
V'ant Hoff Arrhenius Coefficient	1.05
Average Air Temperature (degrees C)	26.10
Maximium Specific Growth Rate (1/day)	0.040
Wet Crop Density (lb/sf)	5.55
Density Adjustment Factor	0.77
Half Rate Concentration (mg/l TN)	6.50
Incidental Nitrogen Loss C_n	0.40
Growing Area (acres)	2.50
Percent Coverage	66.20%
Plant Nitrogen Content (% dry weight)	2.26%
Plant Phosphorus Content (% dry weight)	0.46%
Percent Solids Harvest	9.70%
Plant percent solids	5.00%
OUTPUTS	
Standing Crop (Wet Tons)	200
Field Water Hyacinth Growth Rate (1/day)	0.009
Sloughing Rate (1/day)	0.004
Net Specific Growth Rate (1/day)	0.005
Average Pond Depth (ft)	3.50
Hydraulic retention time (days)	7.92
Average Daily Growth (Wet Tons)	1.8
Average Daily Harvest (Wet Tons)	0.5
Average Daily Sloughing (Wet Tons)	0.8
WHS™ Effluent Total Nitrogen (mg/l)	**2.41**
WHS™ Effluent Total Phosphorus (mg/l)	**0.194**
Nitrogen Removal lb/day	5.79
Nitrogen Removal ton/yr	1.06
Nitrogen Removal Rate lb/acre-day	2.31
Nitrogen Removal Rate gm/sm-yr	94.76
Phosphorus Removal lb/day	0.84
Phosphorus Removal ton/yr	0.15
Phosphorus Removal Rate lb/acre-day	0.34
Phosphorus Removal Rate gm/sm-yr	13.78

Figure 5-25: HYADEM model run for September 2003

HYADEM October 2003

INPUTS	
Influent Average Daily Flow (mgd)	0.46
Effluent Average Daily Flow (mgd)	0.44
Average Total Nitrogen (mg/l)	3.33
Influent Total Nitrogen (mg/l)	4.56
Influent Total Phosphorus (mg/l)	0.40
V'ant Hoff Arrhenius Coefficient	1.05
Average Air Temperature (degrees C)	24.00
Maximium Specific Growth Rate (1/day)	0.040
Wet Crop Density (lb/sf)	5.55
Density Adjustment Factor	0.77
Half Rate Concentration (mg/l TN)	6.50
Incidental Nitrogen Loss C_n	0.40
Growing Area (acres)	2.50
Percent Coverage	69.90%
Plant Nitrogen Content (% dry weight)	2.13%
Plant Phosphorus Content (% dry weight)	0.46%
Percent Solids Harvest	5.40%
Plant percent solids	5.00%
OUTPUTS	
Standing Crop (Wet Tons)	211
Field Water Hyacinth Growth Rate (1/day)	0.010
Sloughing Rate (1/day)	0.004
Net Specific Growth Rate (1/day)	0.006
Average Pond Depth (ft)	3.50
Hydraulic retention time (days)	6.20
Average Daily Growth (Wet Tons)	2.1
Average Daily Harvest (Wet Tons)	1.2
Average Daily Sloughing (Wet Tons)	0.8
WHS™ Effluent Total Nitrogen (mg/l)	**2.93**
WHS™ Effluent Total Phosphorus (mg/l)	**0.145**
Nitrogen Removal lb/day	6.26
Nitrogen Removal ton/yr	1.14
Nitrogen Removal Rate lb/acre-day	2.51
Nitrogen Removal Rate gm/sm-yr	102.55
Phosphorus Removal lb/day	0.97
Phosphorus Removal ton/yr	0.18
Phosphorus Removal Rate lb/acre-day	0.39
Phosphorus Removal Rate gm/sm-yr	15.82

Figure 5-26: HYADEM model run for October 2003

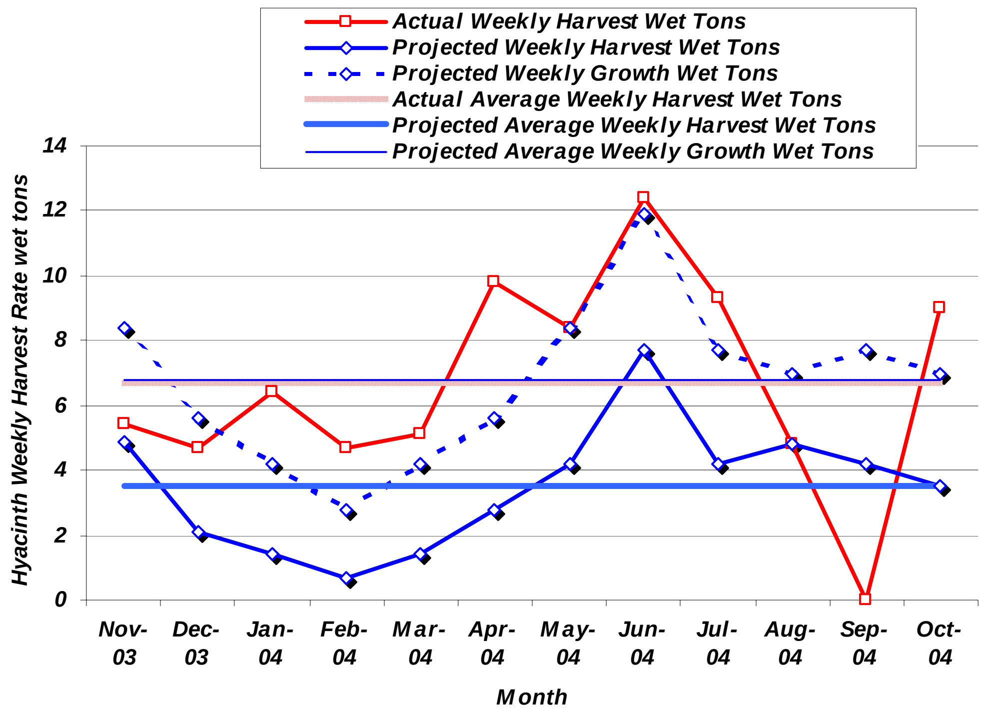


Figure 5-27: S-154 WHS™ actual weekly hyacinth harvest versus HYADEM model projections for weekly harvest and growth by month for the Q4 through Q6 monitoring period.

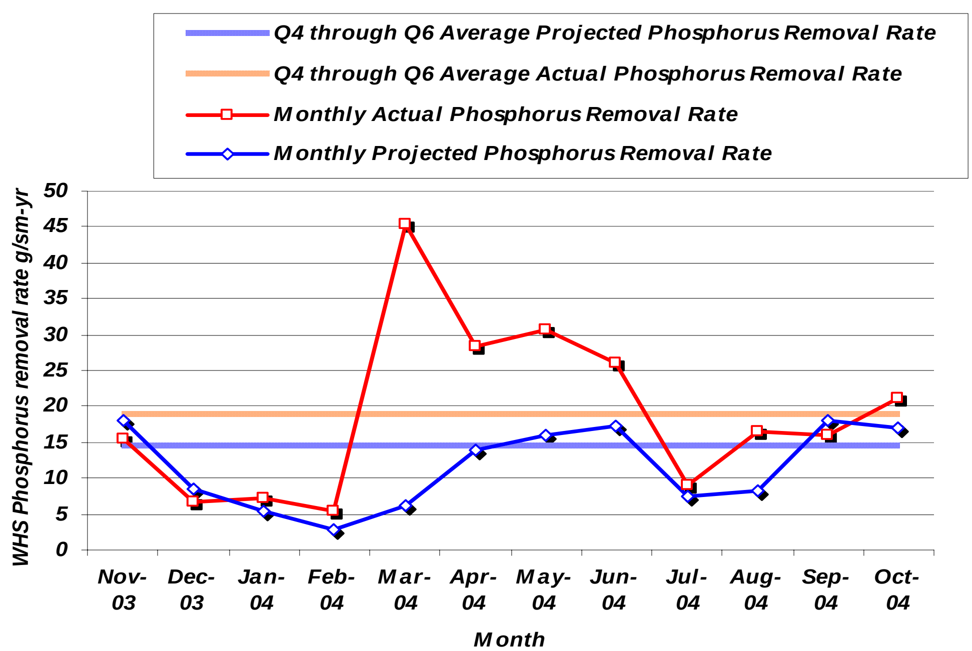


Figure 5-28:. S-154 WHS™ actual total phosphorus areal removal rates versus HYDEM model projections for areal removal rates by month for the Q4 through Q6 monitoring period

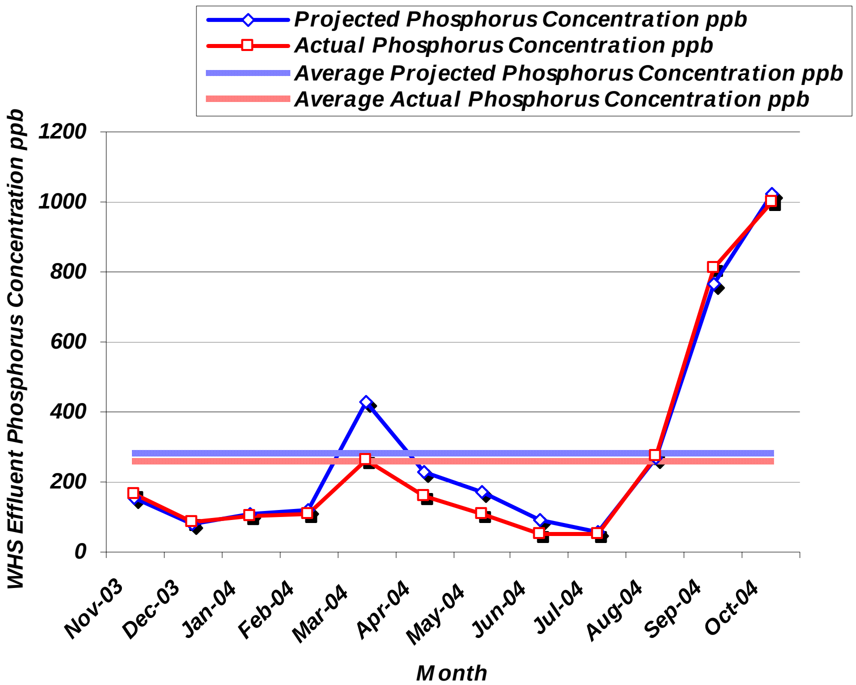


Figure 5-29: S-154 WHS™ actual total phosphorus effluent concentration versus HYDEM model projections for effluent total phosphorus concentration by month for the Q4 through Q6 monitoring period

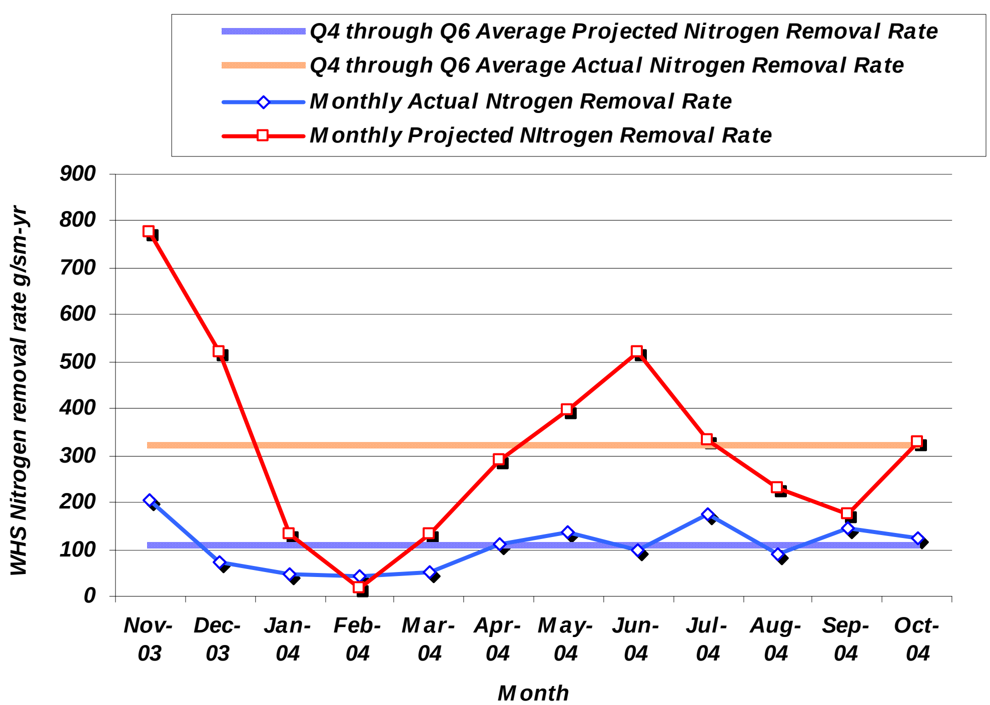


Figure 5-30: S-154 WHS™ actual total nitrogen areal removal rates versus HYDEM model projections for areal removal rates by month for the Q4 through Q6 monitoring period

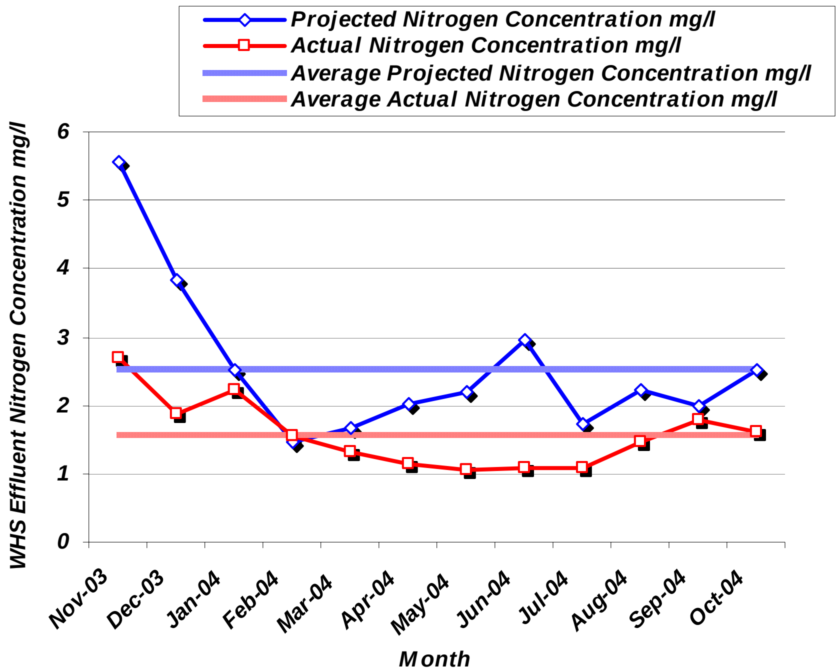


Figure 5-31:.S-154 WHS™ actual total nitrogen effluent concentration versus HYDEM model projections for effluent total nitrogen concentration by month for the Q4 through Q6 monitoring period

Regardless of the ratio of net to gross production, at some time during long-term operations, efforts must include removal and processing of sediment stores within the WHS™ units. When the units are compartmentalized using floating barriers, it becomes practical to intercept these sediments through a small suction dredge. (The use of a permanent perforated manifold has not proven to be sufficiently reliable to ensure satisfactory removal of these sediments.) The dredged material would be pumped to a dewatering or thickening bed, and then further processed through windrow composting, possibly in association with other recovered solids. The costs and solids management aspects of this activity will be included in any cost analysis related to WHS™ systems.

ATSDEM MODEL (ATS™)

Outflow Concentration Optimization Period

In the Preliminary Engineering Report, projections for the ATS™ model were presented, as previously noted herein as Figure 5-2. The model applied at that time was based upon the production estimates, as with HYADEM, with an assigned rather than calculated specific growth rate, of 0.20/day and an assumed sustained standing biomass of 0.007 dry lb/ft^2 or about 34 dry gm/m^2. The projected mean daily productivity was 168.78 dry pounds, or over the entire projected growth area of 2.5 acres (10,121 m^2), about 7.57 dry gm/m^2-day, with an areal phosphorus removal rate of 11.79 gm/m^2-year and an areal nitrogen removal of 54.75 gm/m^2-year. Actual productivity from Q1 through Q3 as measured using the harvest method and the floway coverage method – see Figures 4-6 and 4-7—are noted in Table 5-3. The actual performance of the ATS™ compared to design is shown for each month of Q1 through Q3 in Figures 5-32, 5-33 and 5-34.

Table 5-3: Projected vs. actual production and phosphorus and nitrogen removal rates for ATS™ during Q1 + Q2+Q3

	Model Projection	Q1+Q2+Q3	Actual February	Actual March	Actual April	Actual May	Actual June
Average Daily Flow Influent (MGD)*	0.500	0.424	0.328	0.475	0.413	0.398	0.471
Average Daily Flow Effluent (MGD)	0.500	0.416	0.315	0.463	0.377	0.358	0.463
Influent TP (ppb)	210	170	97	167	111	150	202
Effluent TP (ppb)	40	79	71	97	72	41	71
Average Daily Load TP (lbs)	0.87	0.60	0.26	0.66	0.38	0.50	0.79
Influent TN (ppb)	1.33	2.15	1.93	5.21	2.43	2.75	2.58
Effluent TN (ppb)	0.51	1.68	1.60	1.76	1.73	1.75	1.44
ATS™ Supplemented Nitrogen lb/day	0	2.11	0.36	1.80	2.20	2.00	2.00
Average Daily Load TN (lbs)	5.55	9.71	5.64	22.44	10.57	11.13	12.10
Average Daily Removal TP (lb/day)	0.71	0.33	0.07	0.27	0.17	0.38	0.51
TP Areal Removal Rate** (gm/m^2-yr)	11.79	6.57	1.39	5.38	3.39	7.58	10.17
Average Daily Removal TN (lb/day)	3.41	3.88	1.44	15.64	5.13	5.90	6.53
TN Areal Removal Rate** (gm/m^2-yr)	54.75	77.27	28.68	311.47***	102.16	117.50	130.04
Production through harvest amounts (dry gm/m^2-day)	7.57	2.58	0.11	1.11	4.27	4.77	1.80
Production through floway coverage (dry gm/m^2-day)	7.57	2.77	0.40	0.005	1.23	2.73	3.58

Table 5-3: Continued

	Model Projection	Q1+Q2+Q3	Actual July	Actual August	Actual September	Actual October
Average Daily Flow Influent (MGD)*	0.500	0.424	0.441	0.426	0.389	0.466
Average Daily Flow Effluent (MGD)	0.500	0.416	0.444	0.418	0.413	0.473
Influent TP (ppb)	210	170	312	223	225	200
Effluent TP (ppb)	40	79	124	68	104	76
Average Daily Load TP (lbs)	0.87	0.60	1.15	0.79	0.73	0.78
Influent TN (ppb)	1.33	2.15	2.34	1.70	2.44	2.35
Effluent TN (ppb)	0.51	1.68	1.66	1.66	2.38	2.16
ATS™ Supplemented Nitrogen lb/day	0	2.11	2.10	2.80	2.80	2.80
Average Daily Load TN (lbs)	5.55	9.71	10.71	8.84	10.72	11.93
Average Daily Removal TP (lb/day)	0.71	0.33	0.69	0.56	0.37	0.48
TP Areal Removal Rate** (gm/m^2-yr)	11.79	6.57	13.76	11.15	7.37	9.56
Average Daily Removal TN (lb/day)	3.41	3.88	4.56	3.05	2.52	3.41
TN Areal Removal Rate** (gm/m^2-yr)	54.75	77.27	90.81	60.74	50.18	67.91
Production through harvest amounts (dry gm/m^2-day)	7.57	2.58	4.59	3.22	2.26	2.00
Production through floway coverage (dry gm/m^2-day)	7.57	2.77	1.42	2.33	4.48	2.52

* Influent flow is the WHS™ effluent, which is assumed to incur ½ of water losses/gains.
** Area of actual active area of ATS™ is 8,321 m^2.
*** Outlier data results in higher than expected removal rates.

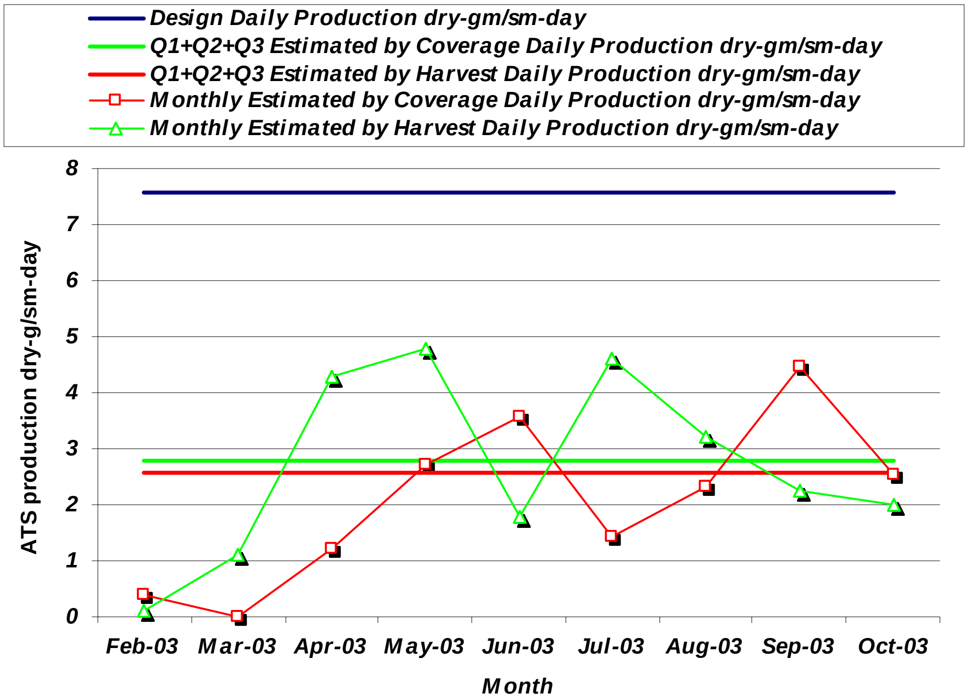


Figure 5-32: Monthly ATS™ actual daily dry production rate versus design model projections for the period the February 2003 through October 2003 monitoring period

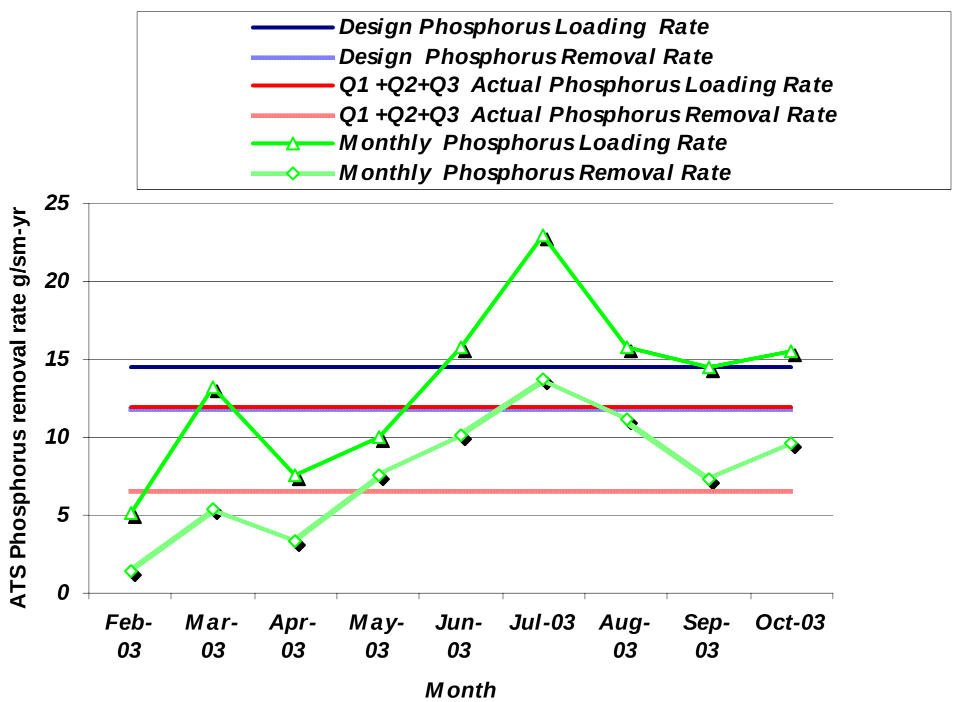


Figure 5-33: Monthly ATS™ actual phosphorus areal loading rate versus design model projections for the period the February 2003 through October 2003 (Q1 – Q3) monitoring period

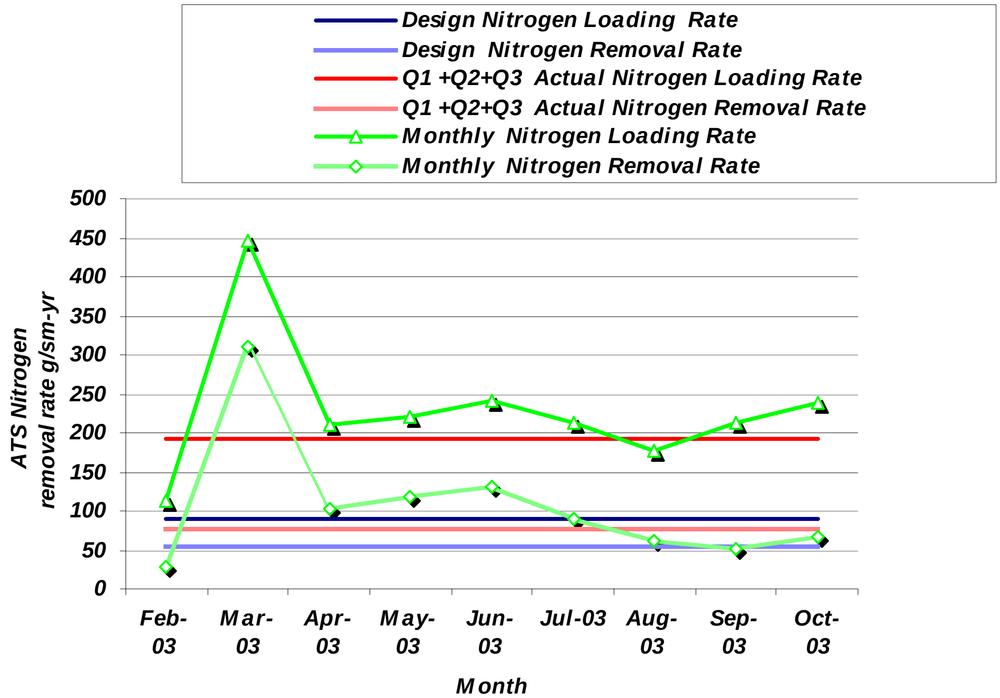


Figure 5-34: Monthly ATS™ actual nitrogen areal loading rate versus design model projections for the period the February 2003 through October 2003 (Q1 - Q3) monitoring period

In general, the lower removal rates observed relate not only to lower phosphorus and linear hydraulic loading rates, but also to lower algal biomass production rates. These lower than expected algal production rates indicate reduced specific growth rates for ATS™ systems. Based on ATS™ research conducted on surface waters south Lake Okeechobee, Adey et al. (1995) documented significantly higher algal production rates at lower nitrogen and phosphorus concentrations, higher LHLR and higher alkalinity than that experienced within the S154 prototype . This is suggestive that some factor other than nitrogen or phosphorus influenced production. As noted previously, this factor could be available carbon, hydraulic loading rates, or a combination of these.[2]

Modeling algal systems at relatively low nutrient levels is recognized as being more challenging than higher nutrient systems e.g. the WHS™. Brezonik (Brezonik, P.L. "Chemical Kinetics and Process Dynamics in Aquatic Systems", Lewis Publishers, pp 505 ISBN 0-87371-431-8) notes this in the following:

"The simplicity of the Monod and cell quota models places limits on their ability to describe nutrient-limited algae growth under transient conditions."

"Steady-state nutrient concentrations ----are very low in many cases and thus difficult to determine accurately. K_s may be below analytical detection limits for some nutrients, making it difficult to the define μ vs. [S] curve. In such cases μ_{max} may occur at concentrations only slightly above the detection limit, and relative large changes in [S] at these low values may not affect μ significantly. Such results invite the conclusion that growth does not follow Monod kinetics, when in reality the problem is analytical."

2 As an extension to this contract three single stage ATS™ floways were established, and provided flow directly from L-62, and higher Linear Hydraulic Loading Rates—5, 10 and 20 gpm/lf. The results of this study is included in a separate report. The findings, provide evidence that flow rate is very influential to algal production. This study is discussed further within Section 5.

In this quote, $\mathbf{K_s}$ is the half rate concentration of the limiting nutrient such that $\mu = 0.5\ \mu_{max}$, and **[S]** is the concentration of the limiting substrate (e.g. carbon or phosphorus). HydroMentia also previously discussed issues associated with modeling algal growth on the ATS™ within a paper included as Appendix 14 in the Q1 Report, and a more detailed review of a comprehensive modeling approach is presented within the S-154 Single-Stage Algal Turf Scrubber® ATS™ Final Report, submitted under separate cover.

As noted, the algae biomass developed slowly during Q1. To enhance the rate of development a nutrient supplementation program was initiated, which included the addition of nitrogen and the reduction of pH through addition of acid in response to elevated pH levels, which occurred as a result of internal recycling on the ATS™. By the end of April, based upon harvest amounts, the productivity for the last week had increased considerably, with a corresponding drop in phosphorus effluent levels to 43 ppb.

During Q2, algae production stabilized to about 3.32 dry gm/m^2-day (with the north floway at 2% slope at 2.98 dry gm/m^2-day, and the south floway at 1.5% slope at 2.80 dry gm/m^2-day), until July 7, 2003. The harvest method and the floway coverage method correlated fairly well during this period as noted within Section 4, with the coverage method typically yielding the higher estimates. After July 7, which corresponds to the disruptive period, the productivity as determined by the floway coverage method averaged only 1.10 dry gm/m^2-day, while the harvest method was 4.90 dry gm/m^2-day. This differential is explained by the virtually complete loss of algae biomass during this period through necrosis and sloughing. The high value for the harvesting method is related to the capture of this sloughed material.

During Q3, algae production returned to about 2.82 dry gm/m^2-day, (with the north floway at 2% slope at 3.25 dry gm/m^2-day, and the south floway at 1.5% slope at 2.38 dry gm/m^2-day). The harvest method and the floway coverage method correlated well during Q3.

If, under a recycle mode, the most influential growth factor is available carbon, not phosphorus or nitrogen, then it would appear reasonable to look at carbon as the Monod factor **S** for purposes of the conditions attendant with Q1 through Q3—i.e. recycle flow, with high pH and water temperatures. Consider for example, the relationship noted within Figure 2-58 and 2-59. From these graphs, the percent available carbon per mg/l alkalinity as $CaCO_3$ can be estimated. Note that the range is from about 26% at pH of 7.5 falling to about 15% at pH 10.0. By making estimates of available carbon at the influent and effluent of the ATS™, and adding any supplemented bicarbonate, the extent of carbon consumption can be estimated and this in turn can be used to project productivity. As noted in Table 5-4, and Figure 5-35, there is a reasonable, but higher, projection of production using the carbon consumption calculation (mean 3.83 gm/m^2-day), when compared to the coverage method (2.83 gm/m^2-day) and the harvest method (2.44 gm/m^2-day). This review is completed for the period from April through October 2003. February and March were considered start-up months and were not considered representative of a stable system. An outlier point from the harvest determined productivity data set, from early May of 15.36 gm/m^2-day was excluded from Figure 5-35 to provide greater resolution. The recycle flow was estimated at 1.0 MGD.

Table 5-4: Estimated carbon consumption rates and productivity on the ATS™ for the April through October 2003 monitoring period

Recycle Flow = 1.0 MGD	Effluent Flow MGD	Alkalinity mg/l as $CaCO_3$	Daytime Influent pH Average	Daytime Effluent pH Average	ATS™ Influent Available Carbon mg/l	ATS™ Effluent Available Carbon mg/l	Added Carbon mg/l	Carbon Consumed gm/m^2-day	Algae production based on Carbon Consumed gm/m^2-day*
4/1/03	0.46	51	8.78	9.65	10.25	8.03	0	1.48	3.21
4/7/03	0.41	49	9.06	9.70	9.16	7.60	0	1.01	2.19
4/14/03	0.43	62	9.28	9.88	10.91	8.74	0	1.41	3.07
4/21/03	0.35	64	8.84	9.73	12.67	9.82	0	1.76	3.82
4/28/03	0.35	39	8.66	9.36	8.07	6.71	0	0.84	1.83
5/5/03	0.34	63	8.37	9.52	13.95	10.33	0	2.20	4.79
5/12/03	0.31	43	8.48	9.66	9.29	6.75	0	1.51	3.29
5/19/03	0.34	49	8.45	9.55	10.66	7.96	0	1.65	3.58
5/26/03	0.45	63	8.95	9.78	12.13	9.51	0	1.72	3.74
6/2/03	0.55	42	9.06	9.75	7.85	6.41	0	1.02	2.22
6/9/03	0.43	44	8.97	10.10	8.43	5.94	0	1.61	3.51
6/16/03	0.41	47	9.18	10.00	8.51	6.58	0	1.24	2.69
6/23/03	0.48	62	8.63	9.82	12.93	9.24	0	2.48	5.39
6/30/03	0.45	51	8.94	10.00	9.84	7.14	0	1.79	3.89
7/7/03	0.42	58	8.81	9.89	11.57	8.44	0	2.02	4.40
7/14/03	0.38	61	8.41	9.78	13.39	9.21	0	2.63	5.72
7/21/03	0.52	54	8.64	9.93	11.23	7.75	0	2.40	5.22
7/28/03	0.48	52	8.58	10.20	10.97	6.76	0	2.84	6.18
8/4/03	0.42	47	9.00	9.80	8.93	7.05	0	1.21	2.64
8/11/03	0.51	41	9.15	9.59	7.93	6.58	0.22	0.83	2.02
8/18/03	0.48	47	8.85	9.59	10.07	7.54	0.39	1.71	3.71
8/25/03	0.47	42	8.78	8.58	9.24	8.86	0.39	0.25	0.55
9/1/03	0.53	37	8.32	8.66	9.05	7.66	0.39	0.97	2.12
9/8/03	0.47	46	7.61	8.82	12.74	9.15	0.39	2.39	5.20
9/15/03	0.30	49	8.45	9.65	11.56	7.72	0.39	2.27	4.93
9/22/03	0.34	53	8.49	9.52	12.30	8.69	0.39	2.20	4.77
9/29/03	0.43	38	8.24	9.32	9.49	6.61	0.39	1.87	4.06
10/6/03	0.34	30	7.89	9.47	8.24	5.00	0.39	1.98	4.31
10/13/03	0.47	30	7.10	8.18	9.35	6.93	0.39	1.82	3.52
10/20/03	0.47	44	8.27	9.01	11.57	8.34	0.79	2.16	4.69
10/27/03	0.41	44	7.45	9.23	13.43	7.85	0.79	3.59	7.80
11/3/03	0.40	44	8.42	9.23	11.32	7.63	0.79	2.34	5.90

* Carbon content of tissue assumed to be 46% dw

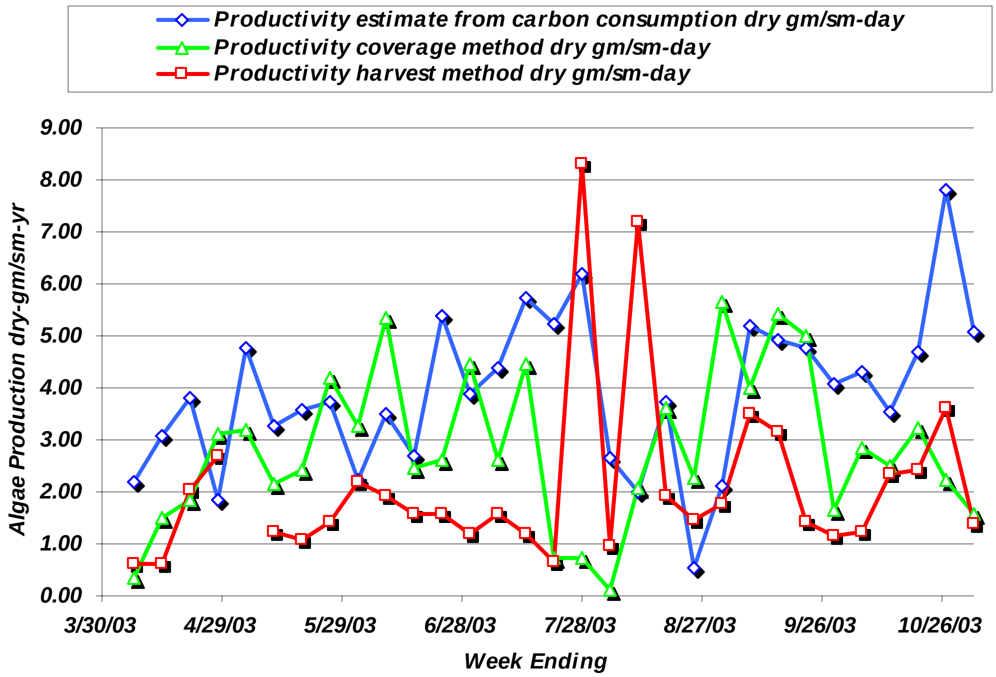


Figure 5-35: ATS™ algal turf productivity based on three different methods (i) Carbon consumption model, (ii) actual algal biomass recovery (Harvest method) and (iii) actual biomass coverage and algal productivity sampling (Coverage method)

In continuing the review of available carbon influences on ATS™ productivity, a review of the data set, exclusive of February and March, and the disruptive period of July, was conducted to estimate specific growth rate. Using these growth rates and carbon as the Monod **S,** a Lineweaver-Burke (1934) evaluation was done in an attempt to estimate both K_S and μ_{max}. Adjustments to the calculated growth rates at varying temperatures were made using the van't Hoff-Arrhenius relationship:

$$\mu_2 / \mu_1 = \Theta^{(T2-T1)} \quad \textbf{(Equation 15)}$$

Where μ_2, μ_1 = specific growth rates at temperatures T_1, T_2 as ^oK

Θ = constant typically between 1.01 and 1.10

In making the temperature adjustments, T_2 was set at the optimal at 307 ^oK, or 34 ^oC. The constant Θ = 1.03 was found to give the best correlation. The Lineweaver Burke graph is noted as Figure 5-36. The x-axis is **1/S** where **S** is available carbon in mg/l, and the y-axis is $1/\mu$ where μ is the temperature adjusted specific growth rate. The y-intercept is set as $1/\mu_{max}$, while the absolute value of the x-intercept is set as K_s**.** The values based upon this analysis are μ_{max} = 0.83/day**,** while K_s = 54.50 mg/l, with $r^2 = 0.46$. A standing crop of 15 dry-gm/m^2 was assumed. Growth rates were calculated by:

$$\mu = \{\ln[(Z_o+h_w)/ Z_o]\}/[7/\Theta^{(307-T1)}] \quad \textbf{(Equation 16)}$$

Where Z_o is standing crop at time = t_0 as dry-gm/m^2
h_w = weekly harvest as dry-gm/m^2
T_1 = Average Daytime Effluent Water Temperature ^oK

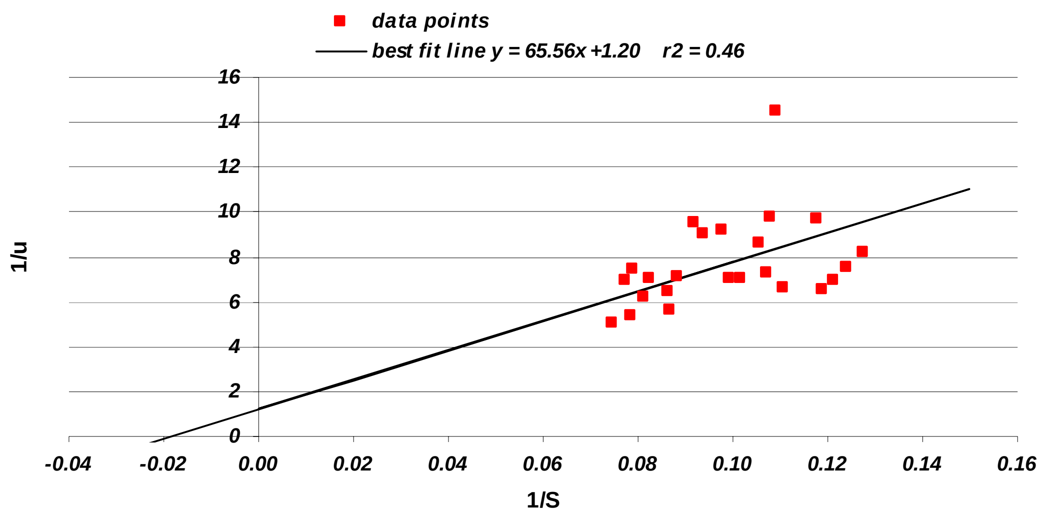


Figure 5-36: ATS™ Lineweaver-Burke Analysis; S = available carbon in mg/l

Based upon the reasonable correlation noted in Figure 5-36, it does appear that at the levels noted within the L-62 flows under the Q1 – Q3 conditions, available carbon imposes a major influence upon the ATS™ when operated with internal recycling and at relatively low LHLR. When this analysis is conducted with this data set, using ortho-P, Total P or Total Nitrogen as the Monod **S,** there is no discernible correlation, with r^2 = 0.03,0.06 and 0.05 respectively.

An ATS™ Design Model, or ATSDEM-RECYCLE, was constructed to allow general assessment of system predictability. This model, as with the HYADEM, relies upon growth kinetics and harvesting to account for the major portion of the nutrient removal. Model runs for April through June and August through October are noted within Figures 5-37 through 5-42, Noted as Figures 5-43 through 5-47 are comparisons between model projections and actual data for harvest quantity, removal rates for nitrogen and phosphorus, and effluent concentrations for nitrogen and phosphorus.

While continued accumulation of data will allow refinements to the ATSDEM model, its application provides a reasonable assessment of the ATS™ performance under recycle conditions. In reviewing the results and graphs, several observations are offered.

1. Consistent with the nutrient budget results, the phosphorus, and to some extent the nitrogen, which was removed through the ATS™ was greater than that accountable within the algae harvest. The model was adjusted to account for this, as with the HYADEM, through an "extra-cellular" loss coefficient, which was assigned the value 0.20 for nitrogen and 0.40 for phosphorus.

2. There are several processes associated with these "extra-cellular" losses. These include the following:

3. Chemical precipitation is an important component for phosphorus reduction, and is associated with pH and cation availability[3]. Floway operating conditions are adjusted such that much of this precipitation occurs at the algae boundary layer. High tissue phosphorus levels confirm that said precipitation is occurring with recovered algal tissue levels ranged

3 The precipitation of predetermined pollutants through adjustment of floway operating conditions such that the pollutant precipitates substantially onto and/or into said cell walls while harvesting a portion of said algal turf onto and/or into which said pollutants have precipitated is a patented process (Patent No. 5,851,398).

from 0.49% to 0.71%. The higher levels indicate precipitation of phosphorus and incorporation into the recovered algal biomass. Floway operating conditions are also adjusted such that precipitation is captured by the algal biomass through a number of physical processes including settling and filtration.

4. Grazing and predation. The ATS™ abounds in small invertebrates, notable amphipods, and to a lesser degree, chironomid larvae. These are preyed upon by shoreline birds (lesser sandpipers, sanderlings etc.). While at first review it may seem unlikely that this could have much influence, it is a factor that should be objectively evaluated

5. Limited retention of nutrient pollutants occurs upon the ATS™ treatment unit in the form of accumulated biomass and precipitants.

6. As with every monitoring program, trace amounts of harvested material may not be accurately quantified. Based on the existing monitoring program, the greatest source of error would likely occur in conjunction with quantification of the microscreen backwash. During the POR, non-recovered algae should be quantified within the effluent itself. Evidence of this occurred in conjunction with heavy sloughing events associated with heavy rainfall—e.g. the nutrient peak in mid September.

7. The ATSDEM-RECYCLE model appears to be conservative, and therefore provides a margin of safety. It also provided a close estimate of biomass recovery (harvest) needs.

8. There is indiscernible influence from atmospheric carbon dioxide, even with the laminar flow and high influent turbulence associated with the ATS™.

Limited discussion has been offered to date in regard to the precipitation of phosphorus within the ATS™ as noted in Item 3.It is known that typical phosphorus metabolic uptake and storage in algae is at values of 0.05% of dry weight for low phosphorus concentrations (in the ambient water) and reaching a maximum of 0.4% at elevated phosphorus concentrations (Adey and Loveland, 1998). In controlled ATS™ units the weight composition of phosphorus may be elevated to 2% or higher, thereby increasing phosphorus recovery by over 500%.

Provided in Figures 5-48 and 5-49 are charts illustrating the relationship between ATS™ outflow ortho phosphorus concentrations and outflow pH as recorded at 0900 hours.

ATSDEM April 2003

INPUTS	
Influent Average Daily Flow (mgd)	0.45
Effluent Average Daily Flow (mgd)	0.42
Recycle Flow (mgd)	1.00
Supplemented Nitrogen lbs/day	1.99
Influent Total Nitrogen (mg/l)	2.13
Adjusted Influent Total Nitrogen (mg/l)	2.70
Influent Total Phosphorus (mg/l)	0.14
V'ant Hoff Arrhenius Coefficient	1.03
Average Daytime Influent Temperature (degrees C)	27.42
Optimal Water T (degrees C)	34.00
Maximium Specific Growth Rate (1/day)	0.830
Half Rate Concentration (mg/l Available Carbon)	54.50
Effluent Alkalinity mg/l as CaCO3	53.00
Influent pH	8.92
Percent Influent Alkalinity as available Carbon	0.19
Influent Available Carbon mg/l	10.28
Effluent pH	9.68
Percent Effluent Alkalinity as available Carbon	0.16
Effluent Available Carbon mg/l	8.27
Bicarbonate Carbon added lbs	0.00
Fixed Carbon lb/day	47.62
Growing Area (acres)	2.50
Incidental Nitrogen Loss Coefficient C_n	0.20
Incidental Phosphorus Loss Coefficient Cp	0.40
Plant Nitrogen Content (% dry weight)	4.64%
Plant Phosphorus Content (% dry weight)	0.57%
Percent Solids Harvest	7.06%
OUTPUTS	
Standing Crop (dry-gm/sm)	15
Specific Growth Rate (1/day)	0.108
Average Daily Production Projected by Growth Rate dry-gm/sm	1.7
Average Daily Projected Harvest wet tons	0.27
ATS™ Effluent Total Nitrogen (mg/l)	**2.09**
WHS™ Effluent Total Phosphorus ppb	**51**
Nitrogen Removal Rate lb/day	2.13
Nitrogen Removal Rate gm/sm-yr	34.92
Phosphorus Removal lb/day	0.31
Phosphorus Removal Rate gm/sm-yr	5.00

Figure 5-37: ATSDEM-RECYCLE model run for April 2003

ATSDEM May 2003

INPUTS	
Influent Average Daily Flow (mgd)	0.44
Effluent Average Daily Flow (mgd)	0.42
Recycle Flow (mgd)	1.00
Supplemented Nitrogen lbs/day	1.99
Influent Total Nitrogen (mg/l)	1.34
Adjusted Influent Total Nitrogen (mg/l)	1.91
Influent Total Phosphorus (mg/l)	0.13
V'ant Hoff Arrhenius Coefficient	1.03
Average Daytime Influent Temperature (degrees C)	31.90
Optimal Water T (degrees C)	34.00
Maximium Specific Growth Rate (1/day)	0.830
Half Rate Concentration (mg/l Available Carbon)	54.50
Effluent Alkalinity mg/l as CaCO3	55.00
Influent pH	8.56
Percent Influent Alkalinity as available Carbon	0.21
Influent Available Carbon mg/l	11.66
Effluent pH	9.63
Percent Effluent Alkalinity as available Carbon	0.16
Effluent Available Carbon mg/l	8.72
Bicarbonate Carbon added lbs	0.00
Fixed Carbon lb/day	47.62
Growing Area (acres)	2.50
Incidental Nitrogen Loss Coefficient C_n	0.20
Incidental Phosphorus Loss Coefficient Cp	0.40
Plant Nitrogen Content (% dry weight)	5.20%
Plant Phosphorus Content (% dry weight)	0.49%
Percent Solids Harvest	5.24%
OUTPUTS	
Standing Crop (dry-gm/sm)	15
Specific Growth Rate (1/day)	0.137
Average Daily Production Projected by Growth Rate dry-gm/sm	2.2
Average Daily Projected Harvest wet tons	0.47
ATS™ Effluent Total Nitrogen (mg/l)	**1.03**
WHS™ Effluent Total Phosphorus ppb	**34**
Nitrogen Removal Rate lb/day	3.08
Nitrogen Removal Rate gm/sm-yr	50.35
Phosphorus Removal lb/day	0.34
Phosphorus Removal Rate gm/sm-yr	5.54

Figure 5-38: ATSDEM-RECYCLE model run for May 2003

ATSDEM June 2003

INPUTS	
Influent Average Daily Flow (mgd)	0.48
Effluent Average Daily Flow (mgd)	0.44
Recycle Flow (mgd)	1.00
Supplemented Nitrogen lbs/day	1.99
Influent Total Nitrogen (mg/l)	1.65
Adjusted Influent Total Nitrogen (mg/l)	2.19
Influent Total Phosphorus (mg/l)	0.18
V'ant Hoff Arrhenius Coefficient	1.03
Average Daytime Influent Temperature (degrees C)	31.60
Optimal Water T (degrees C)	34.00
Maximium Specific Growth Rate (1/day)	0.830
Half Rate Concentration (mg/l Available Carbon)	54.50
Effluent Alkalinity mg/l as CaCO3	52.00
Influent pH	8.96
Percent Influent Alkalinity as available Carbon	0.19
Influent Available Carbon mg/l	9.98
Effluent pH	9.89
Percent Effluent Alkalinity as available Carbon	0.15
Effluent Available Carbon mg/l	7.57
Bicarbonate Carbon added lbs	0.00
Fixed Carbon lb/day	47.62
Growing Area (acres)	2.50
Incidental Nitrogen Loss Coefficient C_n	0.20
Incidental Phosphorus Loss Coefficient Cp	0.40
Plant Nitrogen Content (% dry weight)	4.94%
Plant Phosphorus Content (% dry weight)	0.56%
Percent Solids Harvest	5.13%
OUTPUTS	
Standing Crop (dry-gm/sm)	15
Specific Growth Rate (1/day)	0.120
Average Daily Production Projected by Growth Rate dry-gm/sm	1.9
Average Daily Projected Harvest wet tons	0.41
ATS™ Effluent Total Nitrogen (mg/l)	**1.51**
WHS™ Effluent Total Phosphorus ppb	**93**
Nitrogen Removal Rate lb/day	2.52
Nitrogen Removal Rate gm/sm-yr	41.27
Phosphorus Removal lb/day	0.33
Phosphorus Removal Rate gm/sm-yr	5.46

Figure 5-39: ATSDEM-RECYCLE model run for June 2003

ATSDEM August 2003

INPUTS	
Influent Average Daily Flow (mgd)	0.43
Effluent Average Daily Flow (mgd)	0.45
Recycle Flow (mgd)	1.00
Supplemented Nitrogen lbs/day	2.77
Influent Total Nitrogen (mg/l)	1.60
Adjusted Influent Total Nitrogen (mg/l)	2.34
Influent Total Phosphorus (mg/l)	0.21
V'ant Hoff Arrhenius Coefficient	1.03
Average Daytime Influent Temperature (degrees C)	31.03
Optimal Water T (degrees C)	34.00
Maximium Specific Growth Rate (1/day)	0.830
Half Rate Concentration (mg/l Available Carbon)	54.50
Effluent Alkalinity mg/l as CaCO3	44.00
Influent pH	8.95
Percent Influent Alkalinity as available Carbon	0.19
Influent Available Carbon mg/l	9.17
Effluent pH	9.39
Percent Effluent Alkalinity as available Carbon	0.17
Effluent Available Carbon mg/l	7.50
Bicarbonate Carbon added lbs	8.40
Fixed Carbon lb/day	47.62
Growing Area (acres)	2.50
Incidental Nitrogen Loss Coefficient C_n	0.20
Incidental Phosphorus Loss Coefficient Cp	0.40
Plant Nitrogen Content (% dry weight)	4.83%
Plant Phosphorus Content (% dry weight)	0.71%
Percent Solids Harvest	5.42%
OUTPUTS	
Standing Crop (dry-gm/sm)	15
Specific Growth Rate (1/day)	0.110
Average Daily Production Projected by Growth Rate dry-gn	1.7
Average Daily Projected Harvest wet tons	0.36
ATS™ Effluent Total Nitrogen (mg/l)	**1.74**
WHS™ Effluent Total Phosphorus ppb	**107**
Nitrogen Removal Rate lb/day	2.24
Nitrogen Removal Rate gm/sm-yr	36.73
Phosphorus Removal lb/day	0.38
Phosphorus Removal Rate gm/sm-yr	6.30

Figure 5-40: ATSDEM-RECYCLE model run for August 2003

ATSDEM September 2003

INPUTS	
Influent Average Daily Flow (mgd)	0.36
Effluent Average Daily Flow (mgd)	0.37
Recycle Flow (mgd)	1.00
Supplemented Nitrogen lbs/day	2.77
Influent Total Nitrogen (mg/l)	1.74
Adjusted Influent Total Nitrogen (mg/l)	2.64
Influent Total Phosphorus (mg/l)	0.23
V'ant Hoff Arrhenius Coefficient	1.03
Average Daytime Influent Temperature (degrees C)	29.72
Optimal Water T (degrees C)	34.00
Maximium Specific Growth Rate (1/day)	0.830
Half Rate Concentration (mg/l Available Carbon)	54.50
Effluent Alkalinity mg/l as CaCO3	44.00
Influent pH	8.22
Percent Influent Alkalinity as available Carbon	0.23
Influent Available Carbon mg/l	10.94
Effluent pH	9.19
Percent Effluent Alkalinity as available Carbon	0.18
Effluent Available Carbon mg/l	7.94
Bicarbonate Carbon added lbs	9.80
Fixed Carbon lb/day	47.62
Growing Area (acres)	2.50
Incidental Nitrogen Loss Coefficient C_n	0.20
Incidental Phosphorus Loss Coefficient Cp	0.40
Plant Nitrogen Content (% dry weight)	4.37%
Plant Phosphorus Content (% dry weight)	0.64%
Percent Solids Harvest	4.30%
OUTPUTS	
Standing Crop (dry-gm/sm)	15
Specific Growth Rate (1/day)	0.122
Average Daily Production Projected by Growth Rate dry-gm/sm	2.0
Average Daily Projected Harvest wet tons	0.51
ATS™ Effluent Total Nitrogen (mg/l)	**1.90**
WHS™ Effluent Total Phosphorus ppb	**102**
Nitrogen Removal Rate lb/day	2.28
Nitrogen Removal Rate gm/sm-yr	37.34
Phosphorus Removal lb/day	0.39
Phosphorus Removal Rate gm/sm-yr	6.38

Figure 5-41: ATSDEM-RECYCLE model run for September 2003

ATSDEM October 2003

INPUTS	
Influent Average Daily Flow (mgd)	0.46
Effluent Average Daily Flow (mgd)	0.44
Recycle Flow (mgd)	1.00
Supplemented Nitrogen lbs/day	2.77
Influent Total Nitrogen (mg/l)	2.52
Adjusted Influent Total Nitrogen (mg/l)	3.27
Influent Total Phosphorus (mg/l)	0.20
V'ant Hoff Arrhenius Coefficient	1.03
Average Daytime Influent Temperature (degrees C)	28.42
Optimal Water T (degrees C)	34.00
Maximium Specific Growth Rate (1/day)	0.830
Half Rate Concentration (mg/l Available Carbon)	54.50
Effluent Alkalinity mg/l as CaCO3	38.00
Influent pH	7.83
Percent Influent Alkalinity as available Carbon	0.25
Influent Available Carbon mg/l	10.86
Effluent pH	9.00
Percent Effluent Alkalinity as available Carbon	0.19
Effluent Available Carbon mg/l	7.22
Bicarbonate Carbon added lbs	17.30
Fixed Carbon lb/day	47.62
Growing Area (acres)	2.50
Incidental Nitrogen Loss Coefficient C_n	0.20
Incidental Phosphorus Loss Coefficient Cp	0.40
Plant Nitrogen Content (% dry weight)	4.46%
Plant Phosphorus Content (% dry weight)	0.49%
Percent Solids Harvest	6.24%
OUTPUTS	
Standing Crop (dry-gm/sm)	15
Specific Growth Rate (1/day)	0.117
Average Daily Production Projected by Growth Rate dry-gm/sm	1.9
Average Daily Projected Harvest wet tons	0.33
ATS™ Effluent Total Nitrogen (mg/l)	**2.67**
WHS™ Effluent Total Phosphorus ppb	**122**
Nitrogen Removal Rate lb/day	2.22
Nitrogen Removal Rate gm/sm-yr	36.36
Phosphorus Removal lb/day	0.28
Phosphorus Removal Rate gm/sm-yr	4.66

Figure 5-42: ATSDEM-RECYCLE model run for October 2003

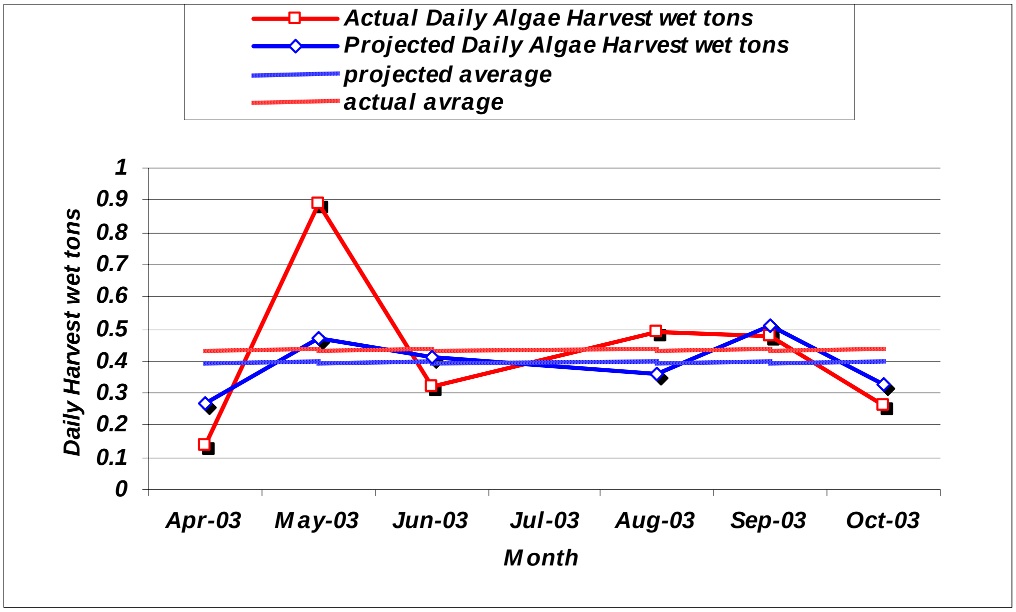


Figure 5-43: ATS™ actual algae harvest versus ATSDEM-RECYCLE model projections for April through October 2003 monitoring period

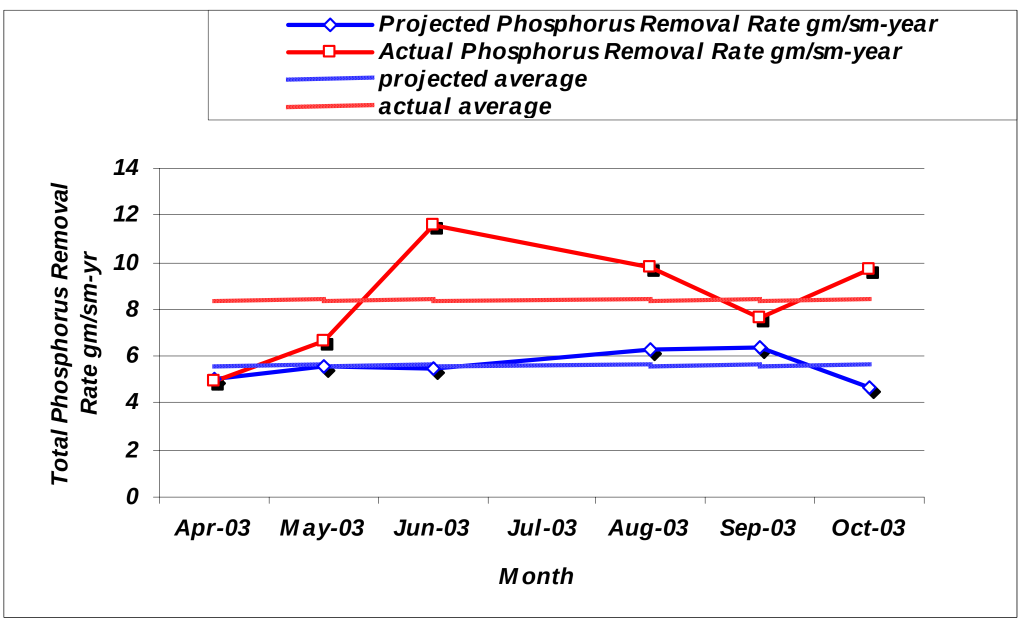


Figure 5-44: ATS™ actual phosphorus areal removal rate versus ATSDEM-RECYCLE model projections for April through October 2003 monitoring period

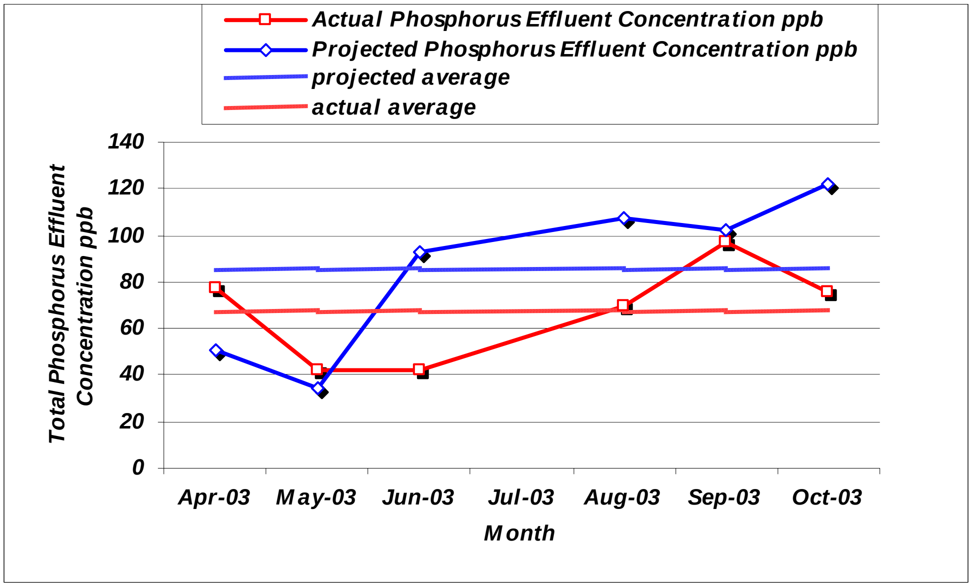


Figure 5-45: ATS™ actual phosphorus effluent concentration versus ATSDEM-RECYCLE model projections for April through October 2003 monitoring period

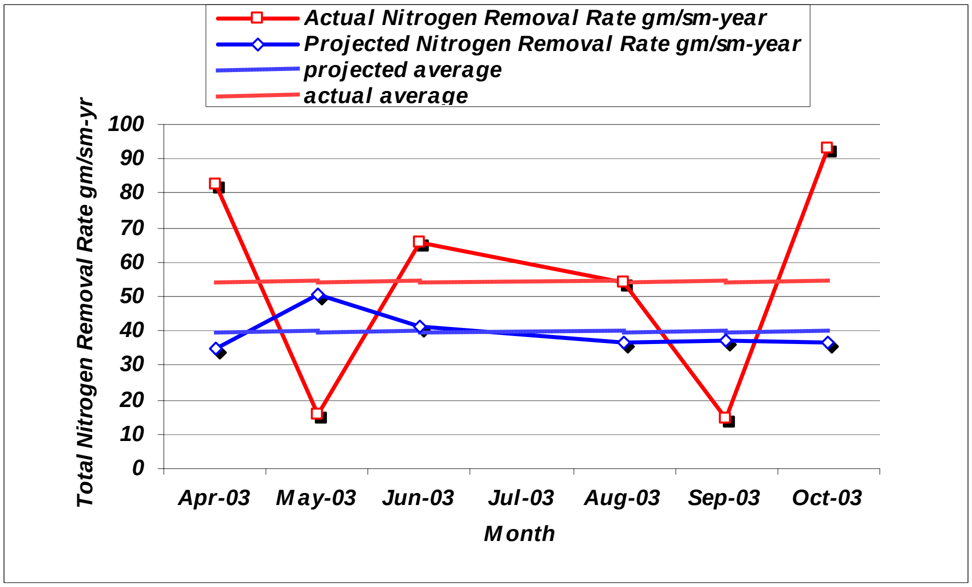


Figure 5-46: ATS™ actual nitrogen areal removal rate versus ATSDEM-RECYCLE model projections for April through October 2003 monitoring period

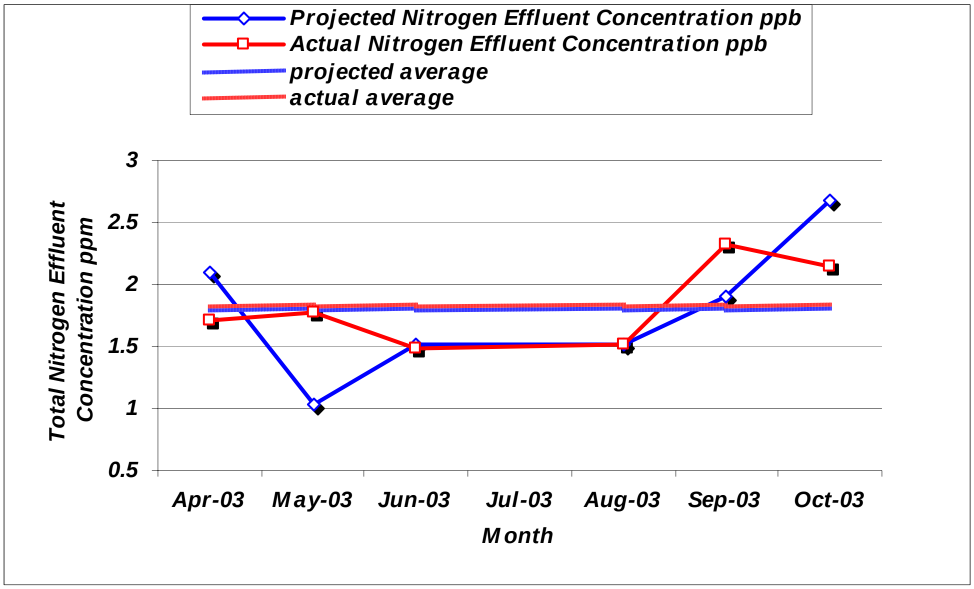


Figure 5-47: ATS™ actual nitrogen effluent concentration versus ATSDEM-RECYCLE model projections for April through October 2003 monitoring period

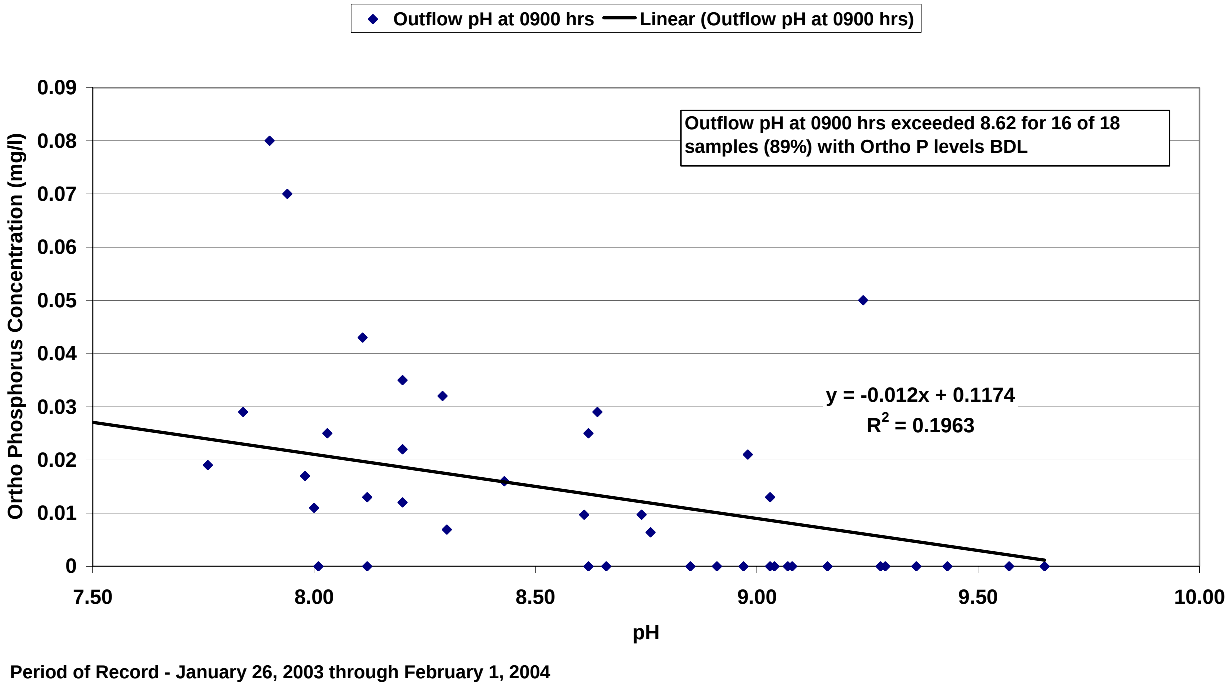


Figure 5-48: ATS™ outflow ortho phosphorus concentration and its relationship to outflow pH at 0900 hours for the period January 26, 2003 through February 1, 2004

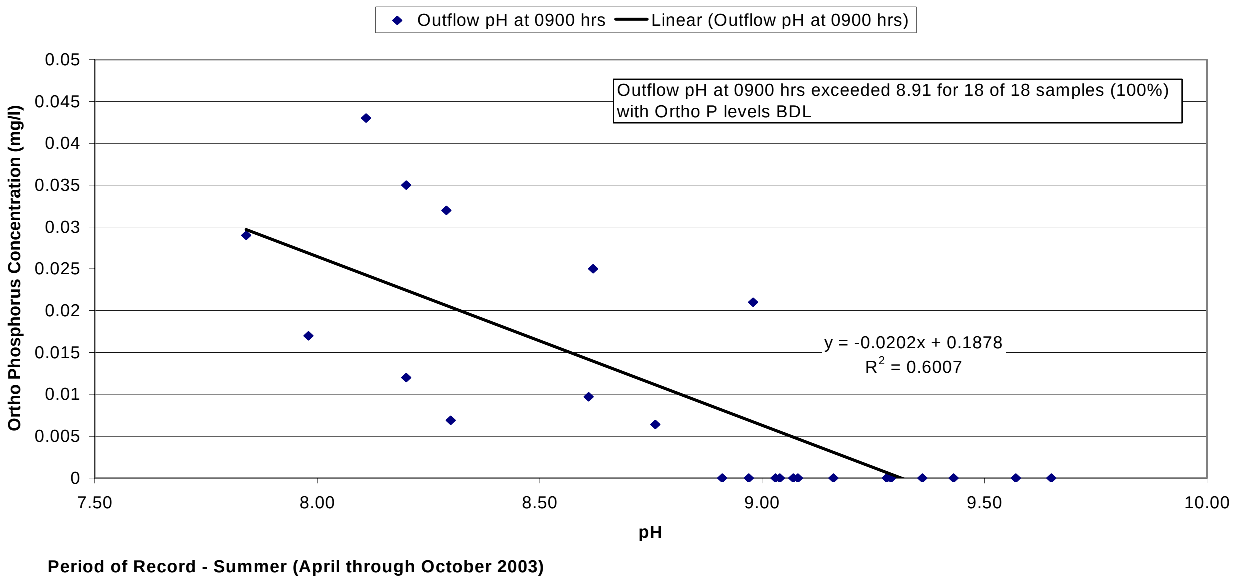


Figure 5-49: ATS™ outflow ortho phosphorus concentration and its relationship to outflow pH at 0900 hours for the period April through October 2003

Load Reduction Optimization Period

For the period Q4 through Q6 (November 3, 2003 through October 18, 2004), the ATS™ demonstrated performance as noted in Table 5-5. On November 3, 2004, the ATS™ system was reduced in area, the flow rate increased, and the recycling of ATS™ effluent terminated. This resulted in a lower influent pH, and accordingly, greater carbon availability. In a parallel analysis, from May 11, 2004 through December 5, 2004, three single-stage ATS™ floways were established, which received L-62 water as a direct feed. A separate report on this single stage system entitled "S-154 Pilot Single Stage Algal Turf Scrubber® (ATS™) Final Report" was submitted in March 2005. Included as a section within this report is development of a revised model (ATSDEM-REV) in which the growth rate and phosphorus removal rate is expressed in a plug flow, first order equation, with phosphorus concentration and LHLR serving as Monod controlling factors, adjusted for temperature. The general relationship is as noted in Equation 17.

$$S_{pp} = S_{pi} - \{[S_t\{Z_o e^{\mu max\ [\{S_{pa}/(Ksp+S_{pa})]\ [(Lp/(Khp+Lp)][24t]\ [1/\Theta^{(Topt-T1)}} - Z_o\}]/V_p\} \quad \text{Equation 17}$$

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
μmax = Maximum growth rate 1/hr
Θ = V'ant Hoff Coefficient
T*opt* = Water Temperature C at optimal growth
T*i* = Water Temperature C during sampling period
S_{pa} = Average 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

Table 5-5: ATS™ performance Q4 through Q6

	Actual Q4	Actual Q5	Actual Q6	Q4+Q5+Q6
Average Daily Flow Influent (MGD)	0.82	0.84	0.78	0.81
Average Daily Flow Effluent (MGD)	0.82	0.83	0.76	0.80
Influent TP (ppb)	118	153	121	134
Effluent TP (ppb)	76	118	94	99
Average Daily Load TP (lbs)	0.81	1.07	0.79	0.91
Influent TN (ppm)	2.48	1.20	1.23	1.60
Effluent TN (ppb)	1.70	1.61	2.32	1.86
ATS™ Supplemented Nitrogen lb/day	1.38	0.08	0.21	0.46
Average Daily Load TN (lbs)	16.78	8.94	7.12	10.34
Average Daily Removal TP (lb/day)	0.29	0.25	0.19	0.25
TP Areal Removal Rate** (gm/m^2-yr)	12.83	12.12	32.03	21.48
Average Daily Removal TN (lb/day)	5.15	-2.20	-7.58	-2.07
TN Areal Removal Rate** (gm/m^2-yr)	228	-107	-1,278	-178
Production through harvest amounts (dry gm/m^2-day)	4.55	3.69	3.95	4.01

As noted within Table 5-5, there is an enhanced total phosphorus removal rate, when compared to Q1 through Q3 (6.57 g/m^2 –yr vs. 21.48 g/m^2 –yr), as well as a noticeable increase in production rate (2.77 dry-g/m^2 –day vs. 4.01 dry-g/m^2 –day). However, during Q5 and Q6, the system was observed as actually contributing nitrogen to the flow. This is presumed to be a result of nitrogen fixation occurring on the ATS™ in response to a paucity of available nitrogen within the WHS™ effluent, which serves as the ATS™ influent. This net internal addition of nitrogen was not observed within the single stage ATS™ systems. In fact nitrogen removal was quite extensive within the single stage operations, amounting to a removal rate of over 700 g/m^2 –yr within the most heavily loaded central floway. The results from Q4 and Q5 provide indication that nitrogen fixation can become an issue in nitrogen poor environments, and needs to be considered in developing nutrient balance projections for low nutrient systems.

It is important to realize that results for Q6 include the period from early September through mid October, which was influenced by the two Category 3 hurricanes (Jeanne and Frances) that hit the facility. In some of the following graphs, data from this period is either excluded or specifically isolated.

Data from Q4 through Q6 was complied, as noted in Table 5-6, to allow comparative total phosphorus effluent projections using ATSDEM-REV. A typical ATSDEM-REV printout is shown as Figure 5-50. The results of these runs are noted in Table 5-6 as well as Figures 5-50 through 5-53.

Table 5-6: ATS™ Q4-Q6 data compilation for ATSDEM-REV analysis

	ATS Influent TP ppb	ATS Area sm	ATS width ft	Influent Flow MGD	LHLR gpm/lf	Water T C	Actual Effluent TP ppb	Projected Effluent TP ppb
11/10/2003	160	3,616	130	0.50	2.68	26.3	120	90
11/17/2003	210	3,616	130	0.64	3.44	24.4	82	146
11/24/2003	160	3,616	130	0.93	4.96	22.8	95	117
12/1/2003	130	3,616	130	0.90	4.80	23.3	75	90
12/8/2003	95	3,616	130	0.88	4.73	12.3	52	91
12/15/2003	82	3,616	130	0.90	4.80	17.0	61	74
12/22/2003	80	3,616	130	0.74	3.94	16.8	63	73
12/29/2003	96	3,616	130	0.83	4.46	13.6	52	91
1/5/2004	110	3,616	130	0.99	5.30	19.9	72	99
1/12/2004	110	3,616	130	0.85	4.57	19.5	77	100
1/19/2004	94	3,616	130	0.87	4.64	15.9	89	89
1/26/2004	90	3,616	130	0.87	4.68	16.9	76	84
2/2/2004	100	3,616	130	0.87	4.65	17.2	84	93
2/9/2004	86	3,616	130	0.91	4.89	20.1	84	76
2/16/2004	120	3,616	130	0.90	4.82	21.8	76	105
2/23/2004	120	3,616	130	0.98	5.27	18.6	69	111
3/1/2004	110	3,616	130	0.90	4.84	20.6	66	98
3/8//2004	220	3,616	130	0.88	4.73	22.1	103	193
3/15/2004	260	3,416	123	0.84	4.74	21.0	164	230
3/22/2004	340	3,416	123	0.87	4.93	22.7	231	198
3/29/2004	230	3,416	123	0.86	4.88	21.3	198	206
4/5/2004	210	3,416	123	0.81	4.60	22.5	157	182
4/12/2004	190	3,416	123	0.44	2.52	21.9	151	171
4/19/2004	140	3,416	123	0.84	4.75	21.7	118	121
4/26/2004	100	3,416	123	0.82	4.66	23.2	98	80
5/3/2004	120	3,416	123	0.77	4.34	21.6	99	103
5/10/2004	100	1,501	54	0.79	10.25	24.0	106	86
5/17/2004	100	1,501	54	0.86	11.03	26.1	141	80
5/24/2004	100	3,030	109	0.86	5.52	26.1	91	81
5/31/2004	110	3,030	109	0.86	5.52	28.3	87	80
6/7/2004	71	3,030	109	0.74	4.75	28.7	120	49
6/14/2004	51	3,030	109	0.96	6.11	27.5	61	37
6/21/2004	63	3,030	109	0.85	5.42	30.1	62	38
6/28/2004	30	1,021	37	0.79	15.06	30.7	46	30
7/5/2004	40	1,021	37	0.79	14.94	31.1	39	30
7/12/2004	47	1,021	37	0.81	15.34	32.6	38	30
7/19/2004	43	1,021	37	0.80	15.18	31.6	39	30
7/26/2004	41	1,021	37	0.83	15.75	29.3	40	30
8/2/2004	80	1,021	37	0.81	15.31	30.3	43	41
8/9/2004	58	1,021	37	0.81	15.44	28.7	56	38
8/16/2004	53	1,021	37	0.52	9.77	30.3	56	30
8/23/2004	340	1,021	37	0.74	13.94	31.1	91	134
8/30/2004	660	1,021	37	0.65	12.37	31.1	527	333
9/20/2004	810	1,021	37	0.74	14.10	31.2	625	380
10/18/2004	1000	1,021	37	0.82	15.59	27.1	961	871

S-154 second stage ATS
1.5% slope Q5 Composite

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
0.015	0.02	0.001314	0.001314	5.38	0.012	0.344	0.02	0.63	0.63

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/m²	Z_0 dry-g/m²	S^*_p Total Phosphorus ppb
22.27	29.9	1.10	37	9.3	0.04	153	14	31.69	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/m²-day	Area per time sequence m²
1	0.344	129	475	16%	300	59	523.59	9	82.55	4.26	0.059

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
0.84	108	0.75	20.28	5%	40%	34.10	1.70	2.13	120	0.0056

Note: Inputs in Blue Print

Figure 5-50: Typical ATSDEM-REV Summary Printout

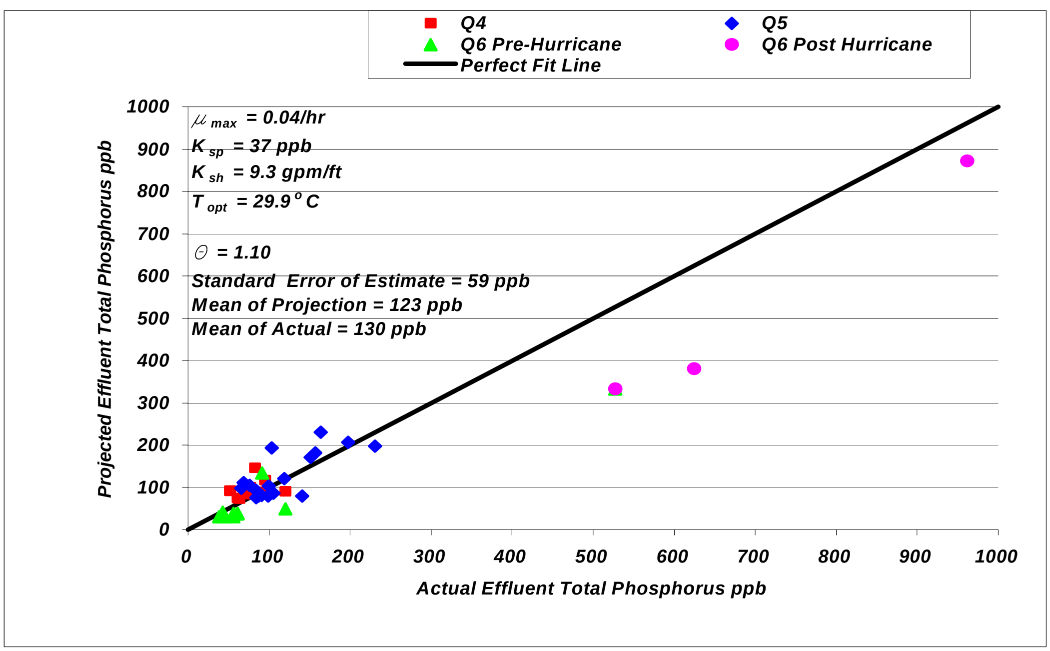


Figure 5-51: ATSDEM-REV total phosphorus projections Q4-Q6

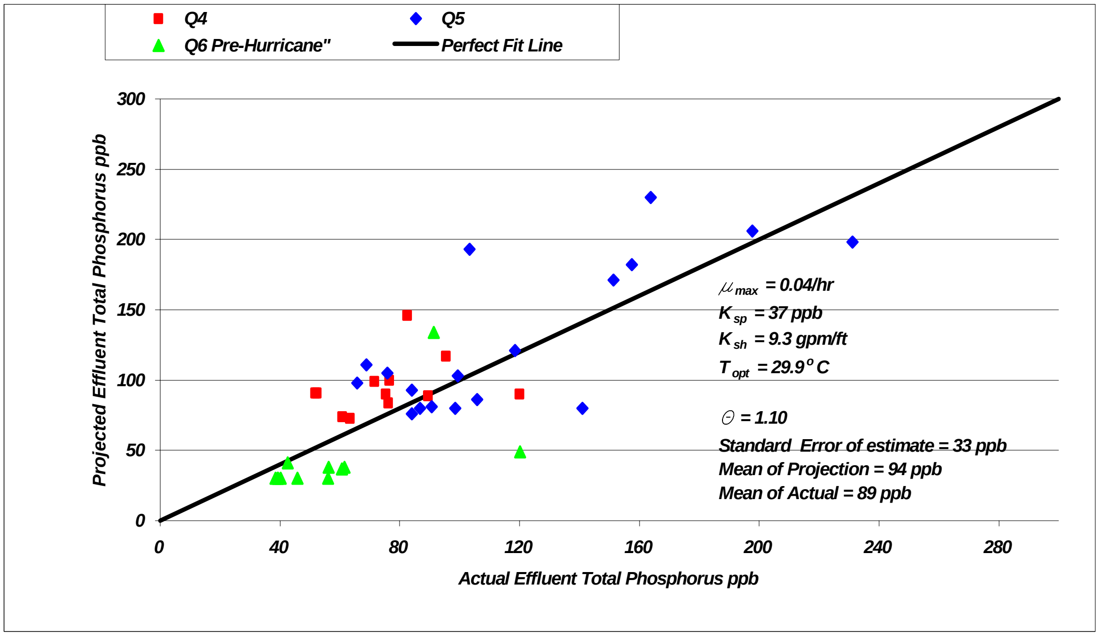


Figure 5-52: ATSDEM-REV total phosphorus projections Q4-Q6 post-hurricane data excluded

Production projections from the ATSDEM-REV model runs compared favorably with Q4 (2.98dry-g/m^2 –day Vs. 4.55 dry-g/m^2 –day). and Q5, (3.37dry-g/m^2 –day Vs. 3.69 dry-g/m^2 –day). However, the projection for Q6 of 17.33 dry-g/m^2 –day is considerably higher than that observed at 3.95 dry-g/m^2 –day. This is consistent with the disparity noted during the warm season associated with the single stage floways, as well as the results from Q1 through Q3. This pattern of lower than projected production during the summer and fall months may be related to unmeasured sloughing during harvest, or from some type of ecological losses, such as grazing and predation. This phenomenon is discussed in the S-154 Single Stage Algal Turf Scrubber® Final Report.

As noted, the ATS™ units experience heavy populations of shoreline birds during the warmer months. Based on bird counts, an estimated 200 birds per day were present foraging during daylight hours during warm months, and 80 birds per day during cooler months. On an annual basis therefore it is estimated that there are an estimated 0.0188 birds/m^2-day foraging during daylight hours on the ATS™. The most common of these shorebirds was the least sandpiper (*Calidris minutilla*), which is noted to have an average weight of about 25 grams. The sandpiper food ingestion rate can be estimated using an allometric equation dependent on body weight (U.S. EPA 1993). The allometric equation used was:

$$IR_{food} = (0.0582 \times BW^{0.651}) \times 1 \text{ kg wet matter}/0.2 \text{ kg dry matter}$$

Where:

IR_{food} = Food ingestion rate (kg/day-wet)
BW = Body weight (kg)

For a typical 25-gram bird, the daily dry weight food intake therefore is 26.4 grams per day. The primary diet of these birds consists of chironomid larvae, other insect larvae, small crustaceans, worms, algae, etc. Assuming that each bird consumes 26.4 dry-grams daily at 3% phosphorus on a dry weight basis, then each bird would remove 0.792 grams of P per day. Based on the typical density of shorebirds foraging on the ATS™, phosphorus removal accounted through bird foraging would equal an estimated 0.01489 g/m^2-day or 5.43 g/m^2-yr.

If the floway receives 0.144 MGD, then the removed phosphorus through predation would amount to 28 ppb, or with an estimated algal tissue level of 0.60% phosphorus, the equivalent algae production of 18 dry-g/m^2-day. Considering these numbers, the grazing activity of birds could very well account for a significant portion of this "lost" algal production. The ATSDEM-REV model needs to be upgraded in the future to account for this facet of the ATS™ dynamics.

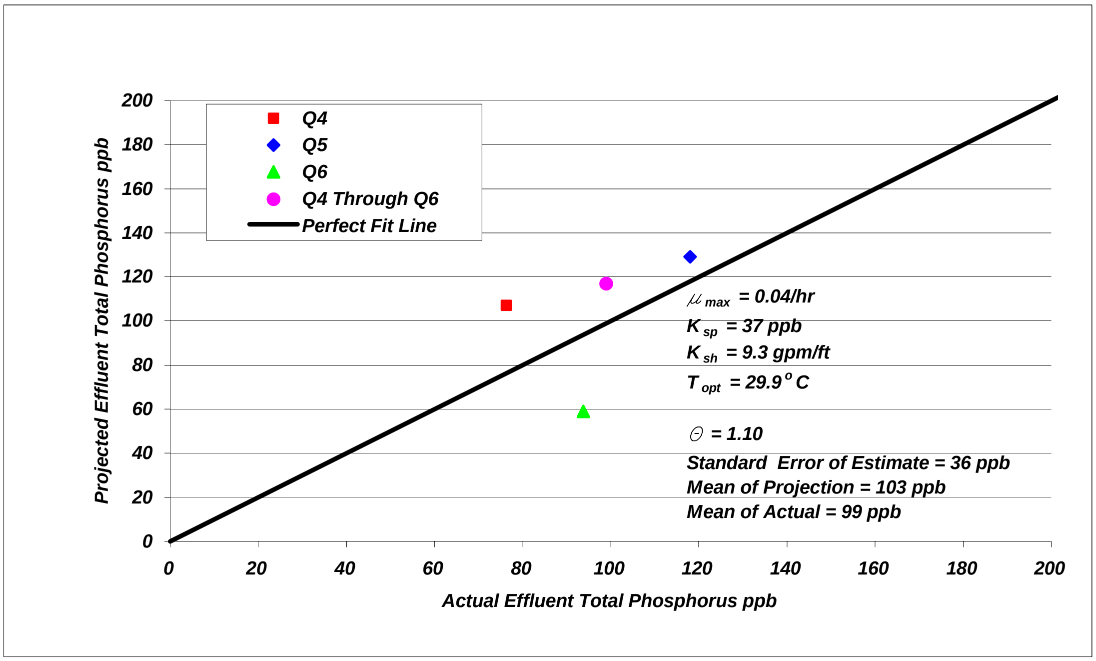


Figure 5-53: ATSDEM-REV total phosphorus projections Q4-Q6 post-hurricane data excluded

SECTION 6. DISCUSSION

INTENT

Several questions have arisen from the review to date of the findings associated with the S-154 ATS™ - WHS™ technology. These have come from District staff as well as from members of the Technical Review Team. Serious attention has been given these questions, as most directly relate to the future application of this technology as part of the District's phosphorus management programs. Each issue is identified within this section, and addressed appropriately.

INQUIRIES THROUGH Q1 REPORT

Question 1

> *The pH, temperature, N:P ratio and dissolved oxygen are all observably higher in the effluent than the influent. Please discuss the mechanisms within the APBWT prototype and the possible implications for the receiving body and ultimately, Lake Okeechobee.*

REPLY 1

The increases in dissolved oxygen and N:P ratio offer real water quality benefits. The present L-62 water is in violation of the historical dissolved oxygen standard of 5 mg/l required for healthy fish and wildlife support—the old Class III standard. The prototype has resulted in effluent levels well above this standard, and at times full saturation. This can only be seen as a benefit of the system.

Similarly, the higher N:P ratio is of benefit, as it moves the balance away from conditions favorable for *cyanobacteria* (previously known as blue-green algae). Blooms of the organisms have proven environmentally problematic in lakes rich in phosphorus and low in N:P ratio, largely because of the ability of many *cyanobacteria* to fix atmospheric nitrogen. This question was brought up at the first Technical Review Committee (TRC) meeting. At the suggestion of the District, we discussed this matter with Karl Havens, a limnologist on District staff. Mr. Havens made it clear that increasing the N:P ratio would be beneficial to Lake Okeechobee. It is noteworthy that the increase in N:P is not due to an increase in nitrogen, but rather the high reduction of phosphorus. Both nitrogen and phosphorus are reduced within the effluent, when compared to the influent, but phosphorus is removed at a greater pace proportionally. Nitrogen is actually added to the system to promote the extensive phosphorus uptake within the hyacinth and algae crops. However, as stated, nitrogen effluent following supplementation remains lower than nitrogen influent.

Regarding pH and temperature there is a potential issue with possible water quality degradation. The effluent pH is notably higher than the influent pH, because of the stripping of carbon dioxide by the ATS™. Comparisons of influent and effluent pH values over both quarters are noted in Table 6-1.

Table 6-1: pH comparison influent and effluent through Q1 and Q2

	Average pH		Maximum pH		Standard Deviation	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
Quarter 1	6.83	8.54	7.54	10.35	0.14	0.92
Quarter 2	6.92	8.94	8.67	10.59	0.58	0.91

It is apparent that not only does the pH increase, but the variability increases also. The effluent consistently demonstrates a pattern of high daytime pH, often above 10.0, with nighttime adjustments to levels more in alignment with the influent. This is a classical pattern associated with high levels of photosynthesis within submerged autotrophic communities, and was anticipated. The issue revolves around the potential environmental impacts of this pH shift. While these fluctuations may not be much different than what is noted in Lake Okeechobee itself, there remains a potential regulatory issue, which needs to be addressed. The resolution of this matter will depend upon the technical assessment of the potential ecological impacts. From an internal operations perspective, several measures can be made which could help modulate pH. For example, a secondary WHS™ system could be used to adjust pH. This secondary system would not only adjust pH but would also modulate temperature. Other approaches could involve reduction of recycling rates over the ATS™, increased hydraulic loading rates, and the use of effluent reservoirs or mixing zones. The issue is one that needs attention, but is not overwhelming in terms of operational, construction, or regulatory demands.

Effluent temperature concerns are not so much with the average temperature, for the effluent in this regard is very similar to the influent. The average influent temperature, as noted in Table 2-11, is actually slightly lower in the effluent, but the degree of fluctuation is significant, with daytime temperatures often reaching above 40 C. It is not certain that this fluctuation would be problematic environmentally, and as with pH, this would need regulatory discussions regarding resolution. Internally, any effluent storage system that provided at least one-day detention would reduce these fluctuations. The methods discussed for pH management would also serve as temperature modulators.

Question 2

> *Discuss how the system would perform if it were optimized for phosphorus load reduction, rather than effluent concentration. Please include possible changes to the configuration and/or operations of the facility, potential phosphorus load reductions, effluent phosphorus concentrations, and changes to water quality standards in the effluent*

REPLY 2

The prototype was designed with the intent of reducing total phosphorus levels to 40 ppb or less. To achieve this it was decided to apply phosphorus at rather low loading rates—about 19 gm-m^2-yr. To date while a clear relationship has been established between loading rate and removal rate, a similar relationship has not been established between loading rate and effluent concentration.

When the influent areal loading rate is considered as C_oQ/A, where C_o is equal to the influent TP concentration, Q is flow rate, and A is process area, then the removal rate is $(C_o - C_e)Q/A$, if we assume Q is approximately the same for influent and effluent. Considering a linear relationship between these two, with removal rate as the dependent variable, then $(C_o - C_e)Q/A = a(C_oQ/A) + b$, with “a” as the slope and “b” as the y-intercept, the data set for Q1 and Q2 as noted in Figure 6-1, fit this well, with a = 0.99 , b = -2.41 and r^2 = 0.95. Interestingly, the suggestion from just this one relationship is that the differential between loading and removal rate is largely represented by the y-intercept value of –2.14 gm/m^2-yr, which may be seen as the internal phosphorus contribution to the system if water with no phosphorus were to be loaded to the system. This is somewhat different from the model used for design when no factor is provided for incidental losses of nutrients—i.e. losses associated with factors other than direct plant uptake. This part of the removal process has been found to be about 29% of the total phosphorus budget, most of which is sedimentation. If the ATS™ and WHS™ systems were loaded more heavily, how would this percentage change?

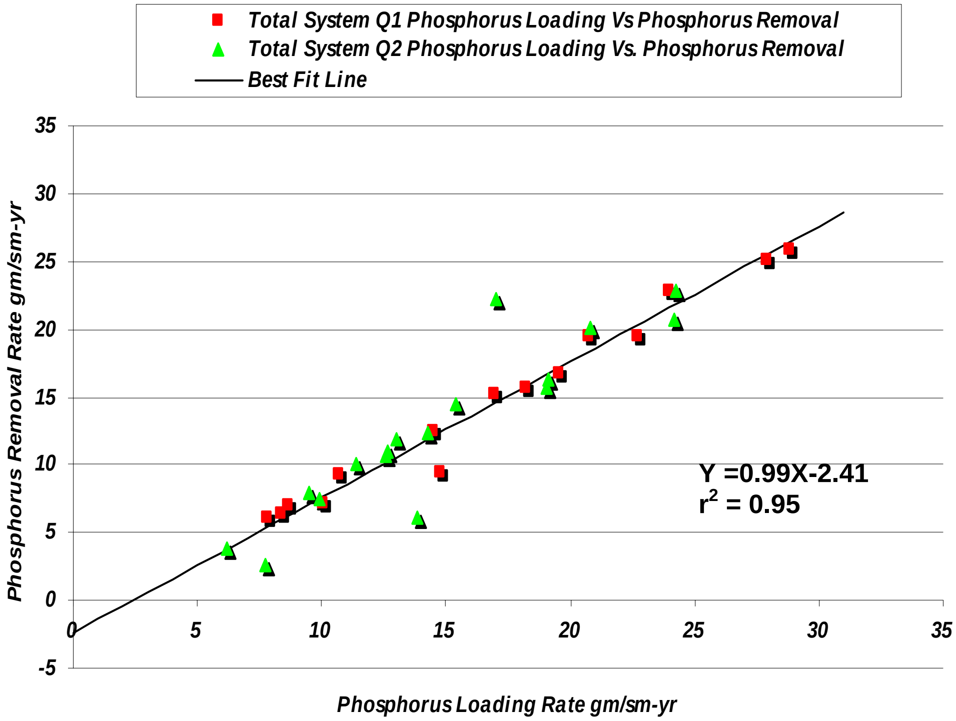


Figure 6-1: Phosphorus loading vs. removal rates for Q1 +Q2

If we look at the relationship to date between phosphorus loading rate and effluent concentration, as noted in Figure 6-2, it is evident that at the current phosphorus loadings applied, little correlation exists between these two elements. This suggests other factors rather than phosphorus loading rate are impacting effluent concentration at the current phosphorus loading rates. This may be plant productivity, mixing influences, concentration of other nutrients, availability of carbon (ATS™) etc. What is the upper loading limit at which loading rate influences effluent concentration? Increasing areal loading rate of course will reduce overall costs, particularly construction costs, so it is beneficial to investigate the right side of these relationships.

As with any biological phosphorus control technology, as phosphorus loadings are increased, at some point outflow concentrations will also increase. This change point in loading rate can be defined as the loading rate value that divides output phosphorus concentrations into uniform and non-uniform regions (Richardson and Qian, 1999). Based on performance of the ATS™ - WHS™ system through Q1 and Q2, phosphorus loads have not been increased to a level that allows identification of this change point zone for the ATS™ - WHS™ system. An illustration of input phosphorus loading effects on phosphorus output concentrations for the North American Wetland Database and S-154 Q1 and Q2 data is provided in Figure 6-3. As projected, due to the recovery of phosphorus via routine biomass harvest within the ATS™ and WHS™ treatment systems, the change point zone for phosphorus loading is significantly higher than that found in treatment wetland systems.

As mentioned in the previous text of the report, there is a possibility that ATS™ design might best be based on carbon availability. Therefore, as suggested, the present system may be oversized for the present carbon loads. This needs to be verified. It is suggested therefore that during the fourth quarter, flows be increased, and the ATS™ be reduced to see if acceptable removal rates and concentrations can be maintained.

Along with increased loads, it is desirable to investigate elimination or at least reduction of recycling to the ATS™. This not only would reduce costs, but might well help in management of the pH and temperature within the effluent. While not feasible for the fourth quarter, another scenario, which could be reviewed during a project extension, would be the use of a secondary WHS™.

During Q4, it is suggested that both primary pumps be activated, so an average flow rate of about 600 gpm can be delivered. It is suggested that only one (1) ATS™ be used initially, and no recycle be included, so that the initial phosphorus-loading rate to the system is increased to about 44 gm-P/m^2/yr.

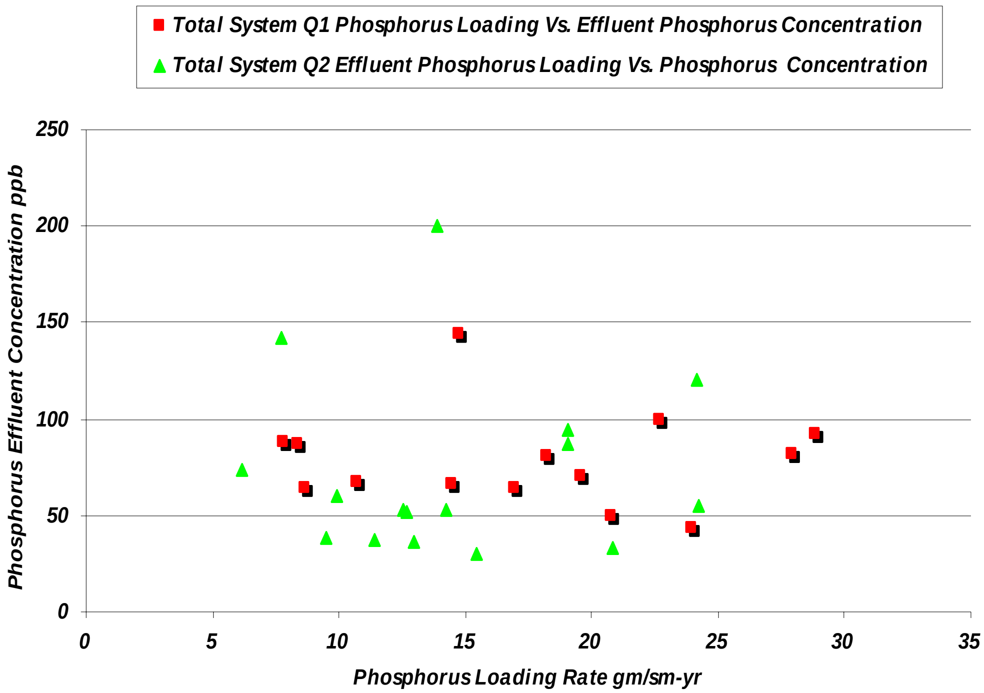


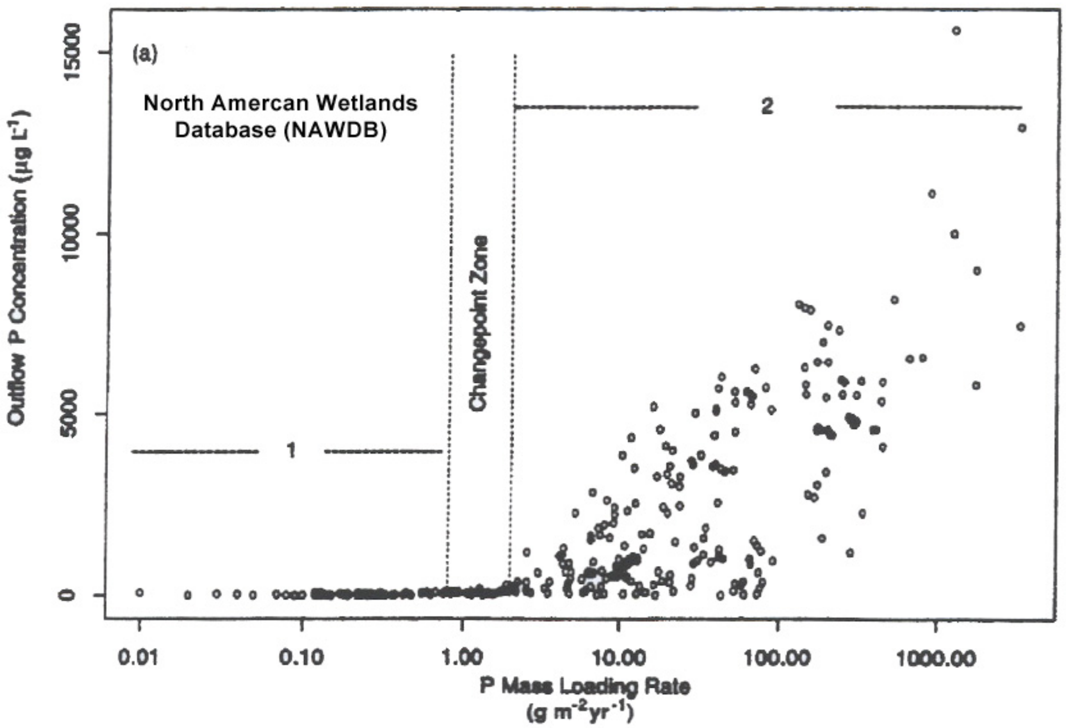
Figure 6-2: Phosphorus loading vs. effluent concentration for Q1 + Q2

Question 3

> *Discuss the ATS™ upset from July, Please include data relating to temperature, pH, nutrient levels, dissolved oxygen, operational (i.e. pH and nutrient management) changes, Water Hyacinth crop densities and WHS™ effluent results, discussion of the pesticides utilized and pesticide lab results and other pertinent information.*

REPLY 3

A complete discussion of the upset—referred to as a disruptive event within the report—is included as part of Section 2 of this report.



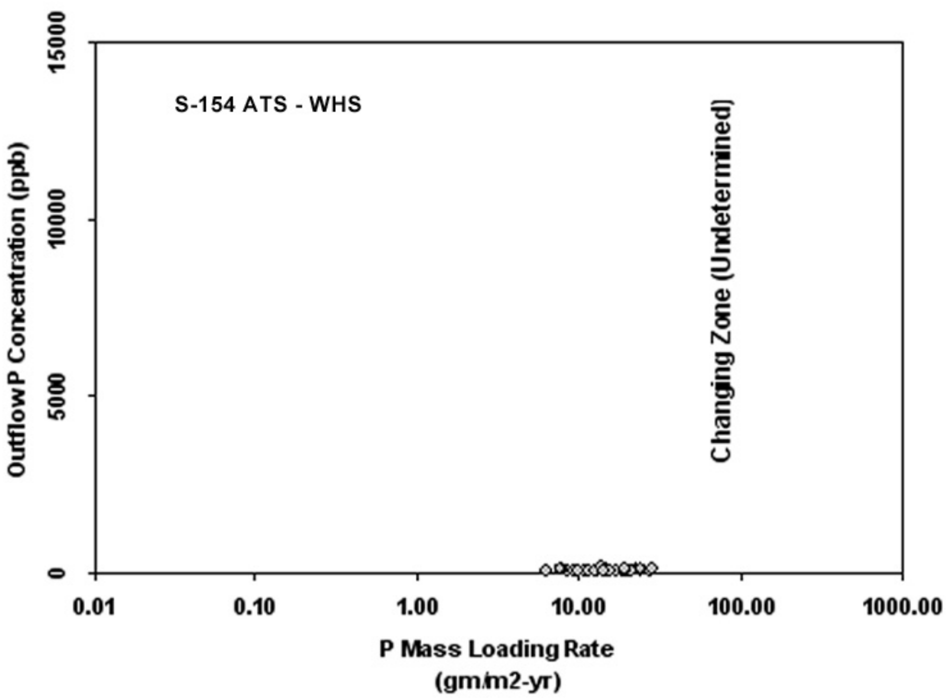


Figure 6-3: Input total phosphorus (P) loading effects on P output concentrations for the North American Wetlands Database (NAWDB) from Richardson and Qian, 1999. and the S-154 ATS™ - WHS™ Prototype for Q1 and Q2 results.

Question 4

> *Please add references to the report. Throughout the 1st quarter report you cited numerous previous studies, data sources, equations, etc. Please reference (especially the equations).*

REPLY 4

References are included within this report.

Question 5

> *Please discuss the appropriateness of combining the 6-day and 24-hr flow weighted data and grab sample data into the same equations. Isn't this giving equal weight to data that should be handled separately? If there is a reference for this, please provide.*

REPLY 5

Within the Operations and Maintenance manual, as submitted to the District on November 21, 2002, is included a water sample analysis laboratory log #19. This includes the combination of the 6 day and 24 hour composite sample results in determining load. This log sheet was upgraded to show flow-weighted concentrations and specific flow rates. Within our original proposal we contemplated determining weekly loads and concentrations from seven 24-hour composite samples. During discussions the District requested flow weighting of samples—in other words take a set sample size following a set amount of flow. This gives a much more accurate assessment of actual concentrations. The District also asked that a seventh day sample be segregated so labile parameters, such as ortho phosphorus and nitrite nitrogen were adequately monitored. This lead to the present sampling regime. There was never contemplated anything but the combining results of the 6-day composite and the 7th day composite samples to develop a weekly load and mean concentration. The equation noted in Section 2 as Equation 2 clearly shows the method in which these samples are combined to calculate weekly loads and concentrations. The equation shows the appropriate weight is given the 7th day sample in relation to the 6-day sample. The grab sample total phosphorus value is not included as part of Equation 2

Regarding ortho phosphorus, since, because of the excessive holding time, this parameter could not be done on the 6-day sample, we had to rely upon the 7th day sample and the grab sample to estimate weekly ortho phosphorus. Rather than use just the value of the 7th day sample as the assumed ortho phosphorus for the entire week, we felt it would be more appropriate to use the ratio of total phosphorus to ortho phosphorus as a means of estimating ortho phosphorus for the week. We used the ratio of both the 7th day sample and the grab sample in establishing this ratio, as noted within Equation 1 of Section 2.

Question 6

> *It may be a good idea to add a definitions section and a list of acronyms at the front of the report.*

REPLY 6

This is included as part of this report.

Question 7

> *Please provide an update and more information o the weevil management plan utilizing parasitic nematodes. Of concern are the issues of whether a permit of some sort was/is required to release this agent, and if, in fact, any of the nematodes are making it through the system to the final effluent. What might be the impacts of the receiving body.*

REPLY 7

A full discussion of this issue is presented within Section 4.

Question 8

> *Please provide a brief discussion of a proposed full scale application of this prototype, including land needs, cost benefit (i.e. $/lb removed) and potential final deposition of harvested material (as discussed at the TRC meeting*

REPLY 8

It is the intent of the prototype to provide sufficient information to permit objective evaluation of the ATS™-WHS™ within a variety of full-scale applications. In the South Florida region alone, several scenarios might well be applied in association with other programs and unit processes to help improve the long-tern effectiveness of the District's overall water management strategy, including programs associated with the Comprehensive Everglades Restoration Program (CERP). Among these would include:

- A stand-alone ATS™-WHS™ system designed as a regional facility to significantly reduce phosphorus and nitrogen loading from major tributaries just prior to release into Lake Okeechobee. Stand alone applications would be most feasible when implementation needs to be expedited; when land needed for passive systems was not available or was too expensive; and when for other reasons the stand alone strategy provides the most cost effective approach.
- As a nutrient attenuation facility in front of passive systems, such as an STA, to reduce loadings to the passive facility, thereby enhancing the ecological value of the associated wetlands while reducing the rate of peat accretion and frequency of residual management within the passive system.
- As a continual nutrient retrieval and recovery system to expedite removal of phosphorus from Lake Okeechobee itself (or other eutrophic lakes), thereby serving to expedite lake restoration and to alleviate the impacts of internal loadings from labile sediment stores from within the lake.
- As an in-line nutrient removal process on the downstream section of major locks or control structures (e.g. along the Kissimmee River) where the change in elevation would provide the head needed to support a stand-alone ATS™ facility.
- As a final polishing unit following passive systems, such as STA's where effluent phosphorus levels needs to be reduced further. This would be particularly important in the Everglades where total phosphorus levels of 10 ppb are required. The S-154 prototype however is not designed to provide the needed testing of performance to these levels, as the water quality is significantly different from the STA effluents associated with the Everglades projects. A prototype to test the system as a polish to one of the existing Everglades STA's has been suggested, and implementation would provide

valuable information needed to establish the full range of capabilities of the ATS™ system. It is likely that a stand alone ATS™ would best serve this particular application.

- On-farm systems to facilitate recovery and internal reuse of nutrients could be practical for larger farms.

One application, which has been discussed as an initial full-scale project, would be location near the present site, in the triangle of land between the S-154 structure and L-62 to the east and the Kissimmee River to the west. A system designed to remove about 24 tons of phosphorus per year from S-154 would require a relatively modest amount of land—from 180 to 320 process acres depending upon the final assessment of the S-154 prototype project removal rates and the degree of conservatism applied to the design effort. At the time the BMP programs significantly reduce loadings associated with S-154, and during dry periods, the system's source water would become the Kissimmee River.

In conjunction with design layout, sizing and cost development for a full-scale treatment system for the Lake Okeechobee Watershed (LOW), the S-154 prototype work needs to be completed, which it is suggested should include at least an 8 month extension of the existing one year investigation period. This additional time is needed to further refine design criteria, including issues such as identification of optimal loading rates and associated removal rates; determining the most efficient process configuration and relative size of the ATS™ and WHS™ units; identification of the most cost effective method of pH and temperature management, to include review of recycling within the ATS™ and the feasibility of a second stage WHS™ or equalization basin; refinement of operational costs and development of an engineering cost estimating program; establishing of firm production costs for livestock feed products and ancillary products, such as compost; and solidifying market strength of these products.

In material previously prepared and submitted to the Lake Okeechobee PDT, general operating costs and sizing information was provided for ATS™-WHS™ based upon past projects and previous experience. The data compiled during the S-154 prototype will be compared to this general information to determine relative conformity, and adjustments will be made to meet the specific conditions associated with S-154 water quality conditions. To date, the S-154 prototype has been operated at loading rates somewhat lower than those provided in this general information. During the fourth quarter, phosphorus loading to the system will be increased to bring condition in closer alignment with the information provided the PDT, and to determine the extent to which removal rates can be increased while ensuring acceptable effluent total phosphorus concentrations.

While the data available to date is not sufficient for completion of a comprehensive economic analysis of the system, some trends and system characteristics have been identified which have design and possible economic implications. The two most notable of these are:

- The ATS™ productivity has shown signs of being carbon controlled, indicating that in addition to the low alkalinity, hence low available carbon, there is a relatively slow movement of carbon dioxide into the water. The influence of both of these phenomenon are exacerbated by the high daytime pH and temperature levels. While adjustment of pH through acid addition has been helpful in making more carbon available and facilitating access to critical trace minerals during the prototype operation, this manner of pH and temperature control is not proposed for full scale systems. Other pH and temperature management approaches therefore need to be investigated, including the reduction or elimination of recycle on the ATS™ (which would significantly reduce electrical costs); reduced ATS™ area; and the possible use of a second stage WHS™ or equalization basin. Energy costs associated with recycle is also significant, and its reduction or elimination would greatly reduce operating costs. Reduction of the ATS™ area would be justified to accommodate design around a carbon rather than phosphorus limitation.

Such a reduction would also lower operating costs, while reducing capital costs substantially. These investigations are vital to expanding upon existent economic cost information.

- The hyacinth harvest has consistently been lower than projected. This is due only partly to slightly lower than projected growth rates. The chopped hyacinths have proven to be lower in moisture and higher in dry solids than projected, often near 9% solids. In addition, the plants are somewhat higher in phosphorus than projected—0.45% vs.0.40%. This means less harvest is needed to remove the same amount of phosphorus. For example at 5% solids and 0.40% phosphorus as dry weight, the amount of harvest required to remove 100 pounds of phosphorus would be 250 wet tons. If the harvest were 8% and 0.45% phosphorus as a dry weight basis, the amount of harvest required to remove 100 pounds of phosphorus would be 139 wet tons. This means that if a palletized product were 85% solid, the amount of water needed to be removed per ton of product would be reduced from 16 tons to 9.6 tons as a result of this shift. If the energy costs of water removal were $5/ton of water, then this represents a potential savings of $32 per ton of product produced. In addition, the labor hours required for harvesting to remove this 100 pounds of phosphorus would be reduced by about 44%. These impacts will be evaluated in further detail in conjunction with a future economic analysis.

Regarding the final products associated with the harvest, it is evident at this time that a livestock feed represents the most feasible and cost effective product at this time. Past efforts have shown the material is potentially an alfalfa substitute (Moreland et al. 1990). Feeding of the greenchop material to heifers over the past 6 months by McArthur farms has shown its palatability. The harvests could be converted to two types of livestock feed products—a dried feed product (bulk, pellets or cubes), and an ensiled product. Drying and pelletizing has the advantage of greater marketing range, which would allow it to be removed quite readily from the basin, and even out of the state. It has the disadvantage of higher production costs, higher equipment costs, and more complex operational demands. The ensiled product could be transported throughout the basin from a bagging complex, and in some cases might be moved out of the basin. It would replace imported feeds, and thus result in a net reduction in imported phosphorus. It would be of lower value than the pelletized feed, but its production would be less complex. Part of the continuing work associated with the S-154 prototype would be to complete a more detailed review of these and possibly other feed production options.

In addition to feed production, incidental residuals would be composted. The compost produced as Batch #2, as identified within Section 4 is a high quality material, which was quite easy to produce. The formulation and the results tracked the design as presented within the Preliminary Engineering Report very closely. While this product would not have the value as a wholesale product when compared to livestock feed, it would be marketable, and might even be amenable to the development of a retail product under the right circumstances and under the direction of a creative marketing scheme. It would not be expected that large quantities of compost would be produced when compared to the feed product, but it is worthy of consideration during the economic analysis.

INQUIRIES THROUGH Q2 REPORT

Question 1

Phosphorus (P) speciation: Phosphorus can be speciated according to chemical state (organic, poly, inorganic). The total P in a water sample can also be classified according to size separation methods, i.e., particulate, colloidal, soluble. Sedimentation can remove settleable fractions of particulate P and sorbed organic or PO_4 *P. Have P size fractions been studied in influent, process water, and effluent? The organic fraction of Total P is a major component in influent and effluent. Is the effluent* *organic P as colloidal materials? Ultrafiltration can be used to size separate colloidal fractions. Sedimentation in WTS is a major removal mechanism, and its significance could be related to the particle size aspect of P.*

REPLY 1

The issue of phosphorus "species" distribution is one that becomes most relevant at low concentrations, and it was considered during the development of the project monitoring plan. Presently both total and ortho-phosphorus are monitored. The ortho-phosphorus is analyzed on a filtered sample, hence is generally represents soluble inorganic phosphorus. The difference between total phosphorus and ortho-phosphorus in considered to be the organic fraction. This organic fraction could be anything from highly labile phosphate loosely affiliated with organic compounds through adsorption; to polyphosphate, to phosphate that is chemically bound to an organic molecule, and is highly recalcitrant. As shown in Table 6-2, within the feed water the ortho-phosphorus fraction represent an average of 69.7% of the total, with the organic fraction at 30.3%, through February 9, 2004.The effluent over the same time period shows a general reversal in this ratio, with 36.6% ortho-phosphorus and 63.4% organic. This clearly indicates preferential removal towards soluble ortho-phosphorus, which would be expected within a biological system. Through 53 weeks of operation, the system has provided 88.3% removal of ortho-phosphorus, and 54.1% removal of organic phosphorus.

Table 6-2: Phosphorus differential through February 9, 2004

	Load lb				Concentration ppb			
	Influent	Percent	Effluent	Percent	Influent	SD (n = 53)	Effluent	SD (n = 53)
Total Phosphorus	579.74	100%	128.97	100%	397	202	79	32
Ortho-Phosphorus	404.42	69.7%	47.24	36.6%	283	173	28	28
Organic-Phosphorus	175.32	30.3%	80.47	63.4%	114	83	51	23

Regarding phosphorus that might be associated with incoming suspended solids, note that the influent suspended solids is relatively low, at 8.20 mg/l. Of this, about 74% is volatile suspended solids (organic). The effluent level is 3.86 mg/l and 3.33 mg/l total suspended and total volatile solids, respectively. The implications are that virtually all of the inorganic suspended solids (sand, precipitants, silts etc) are removed, and 45% of the volatile suspended solids are removed. The total pounds of solids removed through February 9, 2004 are 3,750 pounds. Based upon information on sediments within the region, as completed by Reddy and DeBusk, as well as others, the phosphorus content of the solids would be expected to be perhaps as high as 0.20%. This amounts to a total removal of 7.5 pounds of phosphorus through sedimentation through the period, or 1.7% of the total removed. The indication is that removal through sedimentation when applied to the L-62 source is minimal.

While it is beyond the scope of the present project monitoring plan to conduct more detailed investigations into phosphorus "species" and size fraction composition, this would certainly be a worthwhile investigation. It becomes more important as the need to drive concentrations lower increases, for it is the recalcitrant residual organic portion that will need to be targeted. Removal of this last vestige of phosphorus may require specialized biological and chemical technologies. Certainly within the regions south of Lake Okeechobee this will likely become more of an issue as systems are pushed closer to the 10 ppb total phosphorus target.

Effluent organic phosphorus is most likely colloidal in nature, possible associated with the "color" which is typical of surface waters in this region. However, some of the organic fraction within the effluent may also be associated with either rogue algae from the ATS™, such as diatoms or desmids, or lysed algae cells. Because the total suspended solids in the effluent is very low, the latter is probably more contributory. Some tote tests were done on the effluent in which water hyacinths were applied to attempt further reduction of organic phosphorus. The hyacinths were effective at adjusting water temperature and pH, but less effective at additional phosphorus reduction.

During the 8-month extension period, three individual ATS™ units will be tested on L-62 feed water directly, and loading rates adjusted accordingly to allow assessment of optimal conditions, both in terms of bulk load removal, and final effluent concentration.

Question 2

The report notes different sediment accumulation rates in this WTS versus other hyacinth pods. What fraction of the settled material originates as influent settleable solids? What fraction are the "sloughing" of plant material from the floating hyacinths? Is there a systematic relationship between plant growth and culture characteristics and rate of plant associated sediment accumulation?

REPLY 2

There is included in Section 5, a rather complete discussion of plant sloughing within hyacinth systems, and how it can best be determined and modeled. Staff with HydroMentia has probably given this issue the greatest amount of attention, with findings that sloughing rate is related to net growth rate and of course harvest rate. The fact that about 27% of the hyacinth tissue in non-viable, i.e. necrotic, provides some indication that in equilibrium, the production of necrotic tissue is at about 27% of the new tissue production rate, or sloughing accounts for about 27% of the tissue production. As noted in Table 5-2, the actual sloughing rate, which is labeled k_d , ranged from 18 to 56% of the actual growth rate, averaging 34%. This excludes the month of July, which as an apparent result of the disruptive event, the sloughing rate was 89% of the actual growth rate.

Evaluation of sediment traps set in the ponds indicate a sloughing of about 29,423 dry pounds of solids, and 132 pounds of phosphorus over the three quarter period (January 27 to November 3, 2003). This 132 pounds represents about 34% of the 396 pounds of total phosphorus removed during the POR. However, the nutrient budget indicates that of the phosphorus removed only 24% (96 pounds) is not accountable in plant growth. This provides support to the suggestion that some regeneration (about 36 pounds) of deposited phosphorus occurs back into the water column and into plant productivity.

For the same three quarter time period, the amount of removed suspended solids through the system, assuming most of the settling occurs in the WHS™, was 6,508 pounds, or about 22% of the total accumulated solids. If we deduct these settled solids from the accumulation, the remainder, which is sloughed tissue accounts for about 26% of the hyacinth growth. If these solids, as suggested, are about 0.10% total phosphorus, then the phosphorus attributable to sedimentation of incoming solids is about 6.5 pounds, or 6.8% of the sediment retained phosphorus of 96 pounds. The remaining sediment phosphorus is mostly associated with sloughed tissue.

It is not unusual to see this level of sedimentation in hyacinth systems. As noted, when the influent sediment loads are high, the WHS™ will facilitate additional sediment removal as well. In the initial development of the hyacinth design model (HYADEM) as explained in Section 5, we included an incidental loss coefficient for phosphorus (C_p). This represented phosphorus removed that was not accountable within the crop harvest. Listed in Table 6-3 are several full-scale WHS™ systems, which have been operated by HydroMentia staff [Stewart et al (1987)], showing the value of C_n.

Table 6-3: HydroMentia operated full-scale WHS™ treatment systems and calculation of C_p values

Project	Acres	Influent TP mg/l	Effluent TP mg/l	Flow MGD	C_p	Phosphorus Removal rate gm/m^2-yr
Kissimmee	3.68	1.47	0.27	0.15	0.35	16.8
Orlando Iron Bridge	30	0.74	0.35	8.0	0.30	35.5
Melbourne	12	4.33	3.70	3.0	0.00	53.7
NTC McCoy	1.5	1.97	0.66	0.85	0.50	252.3
Hydromentia Aquaculture	15.5	8.69	8.36	20.0	0.20	143.3
S-154 WHS™	2.5	0.479	0.187	0.42	0.24	14.68

The system shown here with the highest incoming sediment load was the NTC McCoy project—these sediments associated with pin floc from an alum settling tank. Understandably, this system had the highest value of C_p, and the highest removal rate. In this system settling played a major role in phosphorus removal. Interestingly, at the Melbourne project, almost all removed phosphorus was accountable within plant growth, even though solids loadings were rather high. This facility was an old wastewater-polishing pond, and it was noted that stored organic sediments were regenerating significant amounts of phosphorus back to the water column.

The rate of sloughing, as noted in Section 5 depends upon the harvest rate, the growth rate, crop density, seasonal influences and the general crop health. At optimal crop densities, and a mean plant age of 90-120 days, a sloughing rate (k_d) of 0.004/day is a reasonable design value. In conditions where incoming suspended solids were particularly high, then adjustments would be needed to account for the additional sedimentation load.

Question 3

> *Are there phosphorus profiles through the ATS™ floways, and profiles for pH? Phosphorus could decline faster in the upper reaches; then the P gradient would decline as pH increased farther down. Could the floway are be apportioned with a shorter aspect ratio?*

Limited discussion has been offered to date in regard to the precipitation of phosphorus within the ATS™ as noted in Item 3. A more detailed description of this process and its role in optimizing phosphorus removal and recovery will be provided within upcoming reports. Provided in Figures 5-32 and 5-33 are charts illustrating the relationship between ATS™ outflow ortho phosphorus concentrations and outflow pH as recorded at 0900 hours.

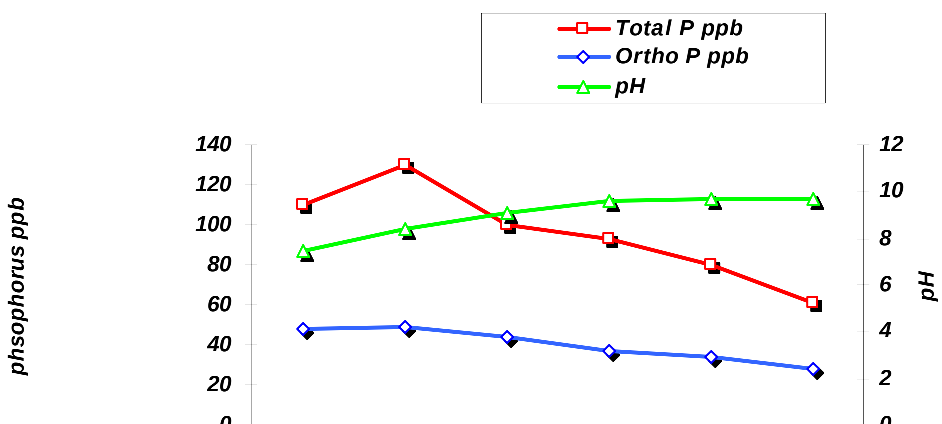
It is known that typical phosphorus metabolic uptake and storage in algae is at values of 0.05% of dry weight for low phosphorus concentrations (in the ambient water) and reaching a maximum of 0.4% at elevated phosphorus concentrations (Adey and Loveland, 1998). In controlled ATS™ units the weight composition of phosphorus may be elevated to 2% or higher, thereby increasing phosphorus recovery by over 500%.

Due to the relatively low concentrations of ortho phosphorus introduced to the ATS™ in the S-154 Prototype, ortho phosphorus being the species of phosphorus most effectively precipitated, operation of the ATS™ has primarily focused on optimization of floway operating conditions for biological growth and metabolic uptake. During the 2004 monitoring period, additional investigations are scheduled to more clearly define the precipitation process as it relates to surface waters in the LOW, and methods for enhancing phosphorus recovery and reducing outflow phosphorus concentrations through adjustments in floway operating conditions.

REPLY 3

There is no provision in the monitoring plan for such additional testing. However, HydroMentia will be conducting limited phosphorus profile monitoring at its cost. Based on previous operation of both research and full-scale ATS™, algal turf productivity remains relativity consistent along the floway, while pH increases as CO_2 is consumed. As floway conditions are modified to enhance precipitation of phosphorus, dependent on influent water quality conditions, phosphorus recovery can vary across the floway. Due to the relatively low concentrations of ortho phosphorus introduced to the ATS™ in the S-154 Prototype, HydroMentia has primarily focused on optimization of floway operating conditions for biological growth and metabolic uptake. During the 2004 monitoring period, additional investigations are scheduled to more clearly define the precipitation process as it relates to surface waters in the LOW. In conjunction with this effort, pH and phosphorus profiles will be collected.

While profile monitoring will be continued, based on preliminary data it appears that significant removal is occurring in the latter stretches of the ATS™, and this removal is expected to attendant more with the precipitation processes than direct productivity. As noted in Figure 6-3, the pH profile, as expected, is rather linear down the ATS™ with a positive slope. The phosphorus profile however seems to change at about 180 feet when the pH exceeds 9.5. What is particularly interesting is that this change, which is an increase in removal, is seen with total phosphorus more than with ortho phosphorus. The implication is that either organic phosphorus is being removed directly, or it is being converted rapidly to ortho-phosphorus, indicating perhaps a pH dependent enzymatic reaction—e.g. alkaline phosphatase. As this is preliminary information, conclusions must be limited until a more complete data set is developed. If this trend is shown to be valid, then full-scale ATS™ units optimized for surface waters in the LOW may include longer floways thereby optimizing uptake and potentially reducing phosphorus outflow concentrations.



	0	60	120	180	240	300
Total P ppb	110	130	100	93	80	61
Ortho P ppb	48	49	44	37	34	28
pH	7.49	8.4	9.06	9.6	9.67	9.69

Distance in feet from ATS influent

Figure 6-3: Observed phosphorus and pH profiles with distance from influent on the ATS™-South floway

Question 4

Carbon dioxide can move from air into the ATS ™ waster by mass transfer across the air water interface. The rate is usually expressed as a product of a mass transfer coefficient and the difference between the actual water concentration and the concentration that would be present in water in equilibrium with the gas phase ($10^{-3.5}$ atm). If the rate of CO_2 mass transfer is not high enough, water levels decline.

REPLY 4

This relationship is recognized, and it was thought that mass transfer of atmospheric carbon dioxide would contribute to the replenishment of consumed carbon within the ATS™. As the mass transfer coefficient is typically related to velocity and turbulence, it was projected that the system operated in a recycle mode would facilitate this transfer, particularly in the surging area. However, based upon the productivity observed (see Section 5) and the rise in pH, it is evident that atmospheric transfer was not nearly sufficient to have a significant influence upon carbon availability. Part of this is likely due to the low equilibrium concentration because of the low bicarbonate alkalinity in the LOW surface waters. For example, consider the equilibrium concentration:

$$[H^+][HCO_3^-]/[\text{Total } CO_2] = K_1 = 10^{-6.35}$$

Where Total CO_2 is dissolved carbon dioxide plus carbonic acid (H_2CO_3).

At a pH of 7.5 then, with a total alkalinity of 55mg/l, the bicarbonate would comprise virtually all of the alkalinity, and the molarity would be 0.000549 or $10^{-3.26}$. Therefore [Total CO_2] = $10^{-4.41}$ or 1.71 mg/l. At pH 9.0, the bicarbonate would have dropped to 80% of the alkalinity or a molarity of 0.00044 or $10^{-3.36}$. Therefore [Total CO_2] = $10^{-6.01}$ or 0.06 mg/l. Considering the general gas transfer equation:

$$dC/dt = (K\,D/z)$$

Where **C** = dissolved gas concentration
D = deficit from equilibrium at time t as mg/l
***z* =** flow depth in cm
and **K** is the mass transfer coefficient in cm/hr

While determining mass transfer coefficients can be challenging, some reasonable estimates can be made. Brezonik (1994) for example notes a coefficient of about 2 cm/hr for CO_2 at low water velocities, and smooth flow. The ATS™ has a mean depth of about 3cm, with an average velocity of about 0.1 fps, or a flow time of 50 minutes down the 300 ft floway, or 0.83 hours. Assuming the initial pH of 7.5 and an initial deficit of 1.71 mg/l, then dC/dt = 1.14 mg/l-hr. This amounts to a mass transfer of about 0.399 pounds/hr at 700 gpm. Obviously algae demands overwhelm this influx, as well as the available bicarbonate in the water, which come available at a rate of about 4.62 pounds/hr to the extent that pH rises considerably down the floway. If all of this carbon were consumed by the algae stock, the production rate over the south floway, considering 12 daylight hours, would approach 15 dry-gm/m^2-day. However, the rising pH not only reduces the mass transfer from the atmosphere, because of a falling equilibrium concentration, but also less of the alkalinity is represented by available carbon as pH increases. In addition, there is likely an inhibitory influence exerted by the higher pH levels. (See Section 5 for a more detailed review of carbon consumption and availability). As noted, atmospheric contribution of carbon is likely minor compared to the alkalinity sources. This could be changed by 1) lowering pH and/or 2) increasing mass transfer coefficient through turbulence etc. Both measures would come with some notable cost.

Question 5

> *The mass balances, such as Figure ES-9, are useful in order to quantitatively account for all the processes by measured flows, concentrations, masses, and also to estimate by difference the mass of P not accounted for. From Figure ES-9, harvested hyacinth accounts for 41% of the total mass P removed while sedimentation accounts for 41%. For the ultimate goal of predicting performance of a full scale system, one can state that sedimentation will occur and is an integral component of the overall P removal process; therefore, sedimentation is one of the significant P removal processes of the treatment system. The gain in the standing crop, however, should be viewed as a "start-up" phenomena that will not be sustained under "steady state" operation.*

REPLY 5

As noted within the discussion offered within Section 5, and as noted throughout the report, sloughing of hyacinth tissue and subsequent loss to the sediments—or sedimentation—is recognized, and always has been recognized as an integral component of the WHS™ dynamic. As discussed, we have in the past assessed such sedimentation through an incidental loss coefficient—which is the fraction of total removal attributable to sedimentation. This has typically been 0.20-0.30, but it will vary, depending upon water quality conditions, design and operational conditions, season, etc. Within Figure ES-9 of the Q2 report is shown all of the accounted for phosphorus, including that which was discharged. The amounts shown we believe indicate 41% of the removed phosphorus as hyacinth harvest, and 31% of the removed phosphorus as sedimentation. For the Q1+Q2+Q3 period, of the 396.77 pounds of phosphorus removed, 183.45 pounds are attributable to water hyacinth harvest, and 75.8% attributable to all harvests and changes in standing crop. Sedimentation during this period amounts to 132.13 pounds phosphorus removal, or 33.3%. Of this sedimentation, some was regenerated back into the water column, or ecological compartments within the system, and of course a portion of it, about 7% of sediment held phosphorus, originated from incoming solids deposition.

The point is well taken—sedimentation, largely resulting from tissue sloughing, is a key component of system dynamics. As with any sustainable biological system, these solids must be managed over the long-term. It is intended that any full-scale MAPS system would include these solids management unit processes. It is noteworthy that all biological systems, even passive systems, need to include a long-term solids management program.

Regarding the "steady state" of the standing crop, it is agreed that design and operational planning should assume that the change in standing crop over time is close to zero. However, during the prototype, in order to effectively set nutrient budgets, the changes in standing crop needs to be included. Please note that a full-scale MAPS operations would not include such extensive monitoring of internal processes as the prototype work. Again, see the model set up within Section 5.

Question 6

Figure ES-7: why are the ortho-P estimated ortho-P.

REPLY 6

Please see explanation offered through Equation 1, in Section 2. The weekly composite sample has too long of a holding time (8 days) for the ortho-P to be reliable. Therefore it is estimated based upon the average ration of TP:OP within the 24-hour composite, and the grab sample.

Question 7

Observations at the pilot showed duckweed in the WTS; how significant is the presence of duckweed

REPLY 7

Gopal (1987) notes that duckweeds--Lemna sp.—"are common associates" within hyacinth stands. He does not note any antagonism between the two species. We have always seen duckweed as a commensal, and it has no obvious impacts. Duckweed, of course does assist in nutrient removal, and is noted for developing particularly high protein levels, which makes it a good feed material. It does not, however, develop a high crop density, when compared to hyacinths, and therefore plays a minor role in process dynamics. Please note that while duckweed is considered a commensal organism, and is not competitive or antagonistic towards water hyacinths, there are plants that are more problematic—these being pennywort (*Hydrocotyl sp.*), alligator weed (*Alternathera sp*.), and other laterally spreading plants such as dayflower (*Commenalis sp.*).These invaders tend to encroach upon space and light availability, and will stress the hyacinth crop. Such encroachments are not seen in an actively managed system to any great extent, because of the high crop turnover. In unmanaged systems however, one can look at such encroachments as part of a successional process, which ultimately will result in a more terrestrial ecology, dominated by woody plants and a diversity of understory plants. In Florida, primrose willow, swamp willow, dog fennel, and even wax myrtle will move in rather quickly once the hyacinth base has been established and stabilized by the understory of pennywort, alligator weed, day flower and cattails. Gopal (1987) describes these communities as sudds. It can be presumed at some point in the evolution of these sudds, the hyacinths become not a nutrient sink, but a nutrient source for overlying vegetation, and in this capacity may be seen as generating a type of "floating" soil. The development of a sudd community is avoided through crop management (The same reasons extraneous pioneer species we call "weeds" are kept out of a lawn through continual mowing.)

Question 8

I was told by a phycologist that algae do not like temperatures above 30 C; that is, their rates slow down. Are the periphytic algae in the ATS™ affected by water temperatures above 30C?

REPLY 8

Periphytic algae and "algal turf" covers a diverse range of species and communities. The evolved capability of these collections of organisms undoubtedly reaches most environmental extremes seen in the biosphere. Accordingly, it is reasonable to expect some collection of adapted algae species to be able to thrive and produce at water temperatures well above 30 ºC. Note or example, the graph labeled as Figure 6-4, that while about 30 ºC appears to be the optimal temperature, substantial phosphorus removal is noted well above 30 ºC. However, it would appear that as water temperature approaches 40 ºC, the performance moves downward. Note that Davis and Ogden (1994) [Everglades: The Ecosystem and Restoration. St. Lucie Press, Delray Beach, Fl] observed high water temperatures associated with periphyton communities (circa 36 ºC) in the Everglades, and noted that some of the species observed are thermophilic, able to thrive in 35-48 ºC. Having noted this, there would appear to be an advantage to maintain water temperatures well below 40 ºC, and preferably close to 30 ºC. The mean effluent water temperature has been maintained below 30 ºC, although peak daytime temperatures in the summer have risen well above 40 ºC. It is thought that recycle flows facilitate heat retainage, and that elimination of recycle will allow these peaks to be avoided.

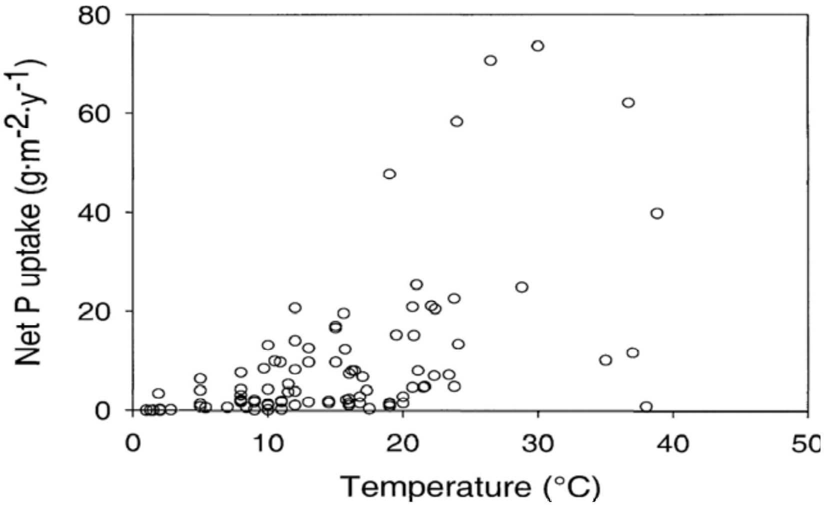


Figure 6-4: Relationship between temperature and calculated net P uptake from W.K. Dodd (2003) "The Role of Periphyton in Phosphorus Retention in Shallow Freshwater Aquatic Systems." *J. Phycol.* ***39*** *840-849.*

Question 9

> *It is interesting that diel variations in water quality parameters seen in the treatment units are not manifest in the L-62 canal water (e.g. Fig.2-30 and 2-31). Why wouldn't canal; water show these trends? Is light attenuation very significant in the highly colored canal; water column versus the very shallow ATS™?*

REPLY 9

Actually, L-62, which is dominated by the floating aquatic plants duckweed (*Lemna sp.)* and water lettuce (*Pistia sp.*) does behave terms of pH, DO, conductivity and water temperature much as the WHS™ system, which is of course also a floating plant system (see Figures 2-46 and 2-58). There are a few submerged aquatic plants in L-62, but productivity of these and of the floating plants are impeded by rather frequent herbicide applications (about six applications in 2003). Without high productivity, of course, the pH and DO swings are not evident. In addition, as noted in the initial stages of the project, a low N:P ratio tends to set up a nitrogen restrained system, and production is accordingly lower than might be expected with such high phosphorus levels.

Regarding light attenuation, it is believed this is more associated with the shading attendant with the floating vegetation than with water color. Incidentally, we have tracked color through the system, although this is outside the scope of work. We have seen, at times, a modest reduction in color (10-30%).

Question 10

> *Page 2-1 Project Objectives. This discusses system operation as to achieve low effluent P concentrations versus operation to achieve high mass removal rates. This is an important issue, that t some extent must be integrated with the goals of the SFWMD. Perhaps the distinction should receive more attention, and be made front and center in the report.*

REPLY 10

Originally, the project was developed to achieve 40 ppb total phosphorus, which was identified in the grant request for proposals as the concentration identified by FDEP at which the ecology of Lake Okeechobee would not be deleteriously impacted. However, after the first Technical Review Team meeting it became apparent that more emphasis was needed on phosphorus removal rates and load removal at this time. Consequently, at the beginning of Q4 we made efforts to increase loading by 1) reducing the treatment area by shutting down one ATS™ unit and 2) increasing influent flow. This will allow assessment of load optimized system, and assist in establishing an upper load removal rate for the L-62 conditions.

Question 11

> *Where is it established that P is the sole rate limiting nutrient? Even though N is supplemented and present in higher effluent concentration, it still may be limiting rates.*

REPLY 11

It is not our intent to suggest that P is the rate-limiting nutrient. In fact, as noted within Section 5, nitrogen is identified as the Monod S component for water hyacinths, while available dissolved carbon is so identified for the ATS™ for LOW surface waters. It is because nitrogen is more of a growth-controlling factor that we supplement it within the L-62 water to optimize phosphorus removal. The challenge of course is to add nitrogen such that it does not “bleed” through, and result in a net release of nitrogen. Therefore we must add enough to attenuate its growth rate impacts, but not enough that the effluent total nitrogen concentration is higher than the influent. In summary, we agree with Dr. Smith that nitrogen is the most influential rate determining factor within the WHS™

Question 12

> *What is a Flex Rake? How does it work? What particle size distribution does it act on?*

REPLY 12

The Flex Rake is a model name for a mechanically clean bar screen device manufactured by Duperon Corporation of Saginaw, Michigan. The particle size (bar separation) is ¼ “. See their website at www.duperon.com for detailed information. This device is used to recover algae filaments during ATS™ harvest.

Question 13

> *There is generally limited discussion of WTS (WHS™) and ATS™ as separate systems that are operating in series. Plots of influent and effluent TP, organic P, PO_4^{-3},do not elucidate the performance of each process.*

REPLY 13

Please note that a great deal of the discussion in Section 2 and Section 5 involve discrete evaluation of the two unit processes—WHS™ and ATS™. Also note that the project scope did not include costs for separate composite sampling of the WHS™ outflow, hence outflow data is based on weekly grab samples in making these discrete evaluations. Please note specifically the modeling effort included as Section 5 of the Q3 report, as well as performance assessments as represented within Figures 2-60, and 2-63 through 2-68.

Question 14

Page 6-4 states that there is little relationship between P effluent concentration and areal P loading rates. One issue here is that Figure 6-2 includes the effects of two different systems: the WHS™ and the ATS™. Is the amount of P harvesting also an influence here? Is the areal uptake rate into plants into plants dependent on the quantity of plants harvested, i.e. the average plant mass removed per surface area per day.

REPLY 14

Within Section 5 of this Q3 report we have made a concerted effort to bring some clarification to this particular issue, i.e. how does harvest rate relate to phosphorus removal rate. As noted in Question 5, the intent is to operate the system such that a working standing crop is sustained at an optimal level, that being at a level when productivity is high and tissue phosphorus content is high, so the phosphorus removal rate is optimized. This standing crop is maintained by harvesting, just as MLVSS is maintained through "wasting" of sludge. This sustained biomass must be nurtured such that it provides needed treatment (removal). If harvesting is greater than productivity, the biomass will decline and treatment effectiveness will also decline. If harvesting is less than productivity, then the biomass will increase, and eventually will occur at a density above optimum. Note that with water hyacinths there is an optimal density—and this relates to access to light for photosynthesis and space for new growth. In Section 5 of the Q3 report we have incorporated a "crop density" factor in the growth kinetics equations.

This question appears also to be an inquiry into the positive feedback issue regarding growth and harvesting. There is little question that harvesting stimulates productivity, as harvesting serves to 1) reduce grazing pressure, 2) sustains optimal crop density 3) eliminates diseased or senescent plants and 4) maintains an crop of young plants by sustaining a low Mean Plant Age (MPA).

Question 15

For WTS, P assimilation into harvested plants is the main vector for P removal that the WTS is meant to enhance. The quantity of plants harvested, i.e., the average plant mass removed per surface area per day, is quite significant.

REPLY 15

It is presumed that WTS mean Water Treatment System, and has been used within these inquiries to mean the WHS™ component. Question 15 is actually a statement, with which we agree—that being that harvesting of the crop as a continuous routine is the central dynamic responsible for phosphorus removal.

Question 16

Fig 3-1: not clear what is being plotted here. According to the figure, as the specific growth rate increases, the standing crop declines. There is a mass balance that has to be built into such calculations.

REPLY 16

The exercise associated with Figure 3-1 is related to the estimation of a standing crop in the ATS™. It is very difficult in the field to determine the standing crop of algae because 1) when collection is made, much of the single cell algae is easily lost as it detaches from the filaments and enters into suspension with the water 2) it is difficult to dislodge all of the algae effectively during sampling, and 3) the nature of the standing crop varies considerably down the floway. To estimate standing crop, we considered the first order kinetics equation:

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

Where Z_t, Z_0 are standing crop at times **0** and **t**,
and μ is specific growth rate 1/day.

When $Z_t = Z_0 + h_t$

Where h_t is the harvested biomass at the end of time **t,** which in this analysis was seven days, then $\{\ln[(Z_0 + h_t)/ Z_0]\}/t = \mu$. It is this relationship that is plotted, with the two variables Z_0 and μ being examined through a range of practical values—noting that h_t is known. The shaded area shows the range of reasonable values. The conclusion is that while we do not know exactly what the standing crop is on the ATS™, through the range of practical values, it represents a small amount of phosphorus when compared to other compartments, such as harvested biomass or hyacinth standing crop. It is noteworthy that we have the same challenge when establishing modeling conditions, per Section 5. A standing crop of 15 dry gm/m^2 or about 275 dry pounds over the entire ATS™ was used as a reasonable estimate.

Question 17

It appears that the HYADEM model simulation results were compared to the performance of the WTS-ATS™ system (Figure 5-1). Is this the case? Is not the HYADEM model for water hyacinth aquatic treatment systems, and not hyacinth ponds followed by ATS™ units.

REPLY 17

Please note that Figure 5-1 refers only to the hyacinth (WHS™) system. Figure 5-2 is the follow-up design model for the ATS™. In Q3 we have clarified the modeling of the two systems separately by presenting model runs for each month the HYADEM, and through an ATS™ version, we call in the Q3 report, ATSDEM.

Question 18

Page 4-4. For the time period before the disruptive period of May 5 to July 7, viable biomass is:

*Start May 5 standing crop = 0.7452*200.23 = 149.21 wet tons*
*End July 7 standing crop = 0.7249*221.21 = 160.35 wet tons*

Average standing crop = (149.21+160.35)/2 = 154.78 wet tons
*Wet tons harvested during time period = 0.7634*79.71 = 60.85 wet tons*
Average wet tons harvested per day = 60.85/63 = 0.966
Net increase in viable mass = ending mass – starting mass +harvest
= 160.35 –149.21 + 60.85
= 71.99 wet tons
Including the increase in standing viable biomass in the harvesting

Average MPRT = 154.78/(71.99/63) = 135.4 days or u =0.0074 day^{-1}.

Is this calculation valid? If so, why is the WTS managed with such low growth rates? Is it possible to perform more of these type calculations to determine performance potential? Was the system ever in any kind of "steady" condition? The first period in Q2, after the Q1 hyacinth grow out, but before the upset, appears to be the most useful data set. Is it? Can the performance of hyacinth pond be separated out from the algal turf scrubber?

REPLY 18

These calculations were made; using what is presented in the Q3 report as Equation 11, as shown below.

$$Z_t = Z_0 e^{U(th1 + th2 + ...+ thn)} - h_1 e^{U(th2 + th3 + ...+ thn)} - .... - h_{n-1} e^{U(thn)} - h_n \quad \textbf{(Equation 11)}$$

This relationship provides a little more precision to the calculation of growth rate. The calculation of growth rate for Q3, as noted in the report is 0.0079 day^{-1}. In looking at the presentation provided in Section 5, this growth rate represents a net growth rate. If we add to this the sloughing rate, which is similar to the endogenous respiration rate used for activated sludge, a value of 0.004day^{-1}, we find a gross specific growth rate of 0.0083day^{-1}. If the total biomass, i.e. viable plus non-viable is used, the growth rate for Q3 is calculated at about 0.010 day^{-1}. Using the HYADEM model as the base and total biomass, the projected rate for the period is just under 0.010 day^{-1}, as noted in Table 5-2 of the Q3 report. In summary, the growth rate during Q3 was about as expected.

The issue brought up in this inquiry is well taken. How can productivity and growth rate be increased or optimized? Obviously the key is plant health and maintaining adequate nutrients and proper environmental conditions. There certainly is a significant difference between long-term field values related to growth and what is found in short-term, isolated bench scale or mesocosm studies. For example, Musil and Breen (1979) in their classic study on hyacinths developed through the Lineweaver-Burke analysis a μ_{max} of over 0.10 day^{-1}, while we have found 0.04 day^{-1}, as the practical field based μ_{max}. Much of this difference relates to the challenges an unencumbered large-scale crop faces regarding grazing, intra-specific competition; wide fluctuations in water quality, climate, and environmental conditions. For example the wind alone can create density stresses, and mechanical damage to above water biomass. This difference between small-scale and large scale has always been a factor when systems are operated on a commercial level. Mesocosm studies are helpful in establishing genetic capabilities, but not emulative of large-scale conditions.

Note that the performance of the WHS™ and ATS™ are evaluated separately, and discussed separately within Section 5 of the Q3 report. Regarding "steady" conditions, even with the disruptive period in July, the WHS™ system has been maintained in a rather "steady" condition, with the total biomass averaged 190 wet tons, with sd = 23 wet tons, n = 31. If the disruptive period of July is removed, the average is 195 wet tons, with sd = 20 wet tons, n = 27. Considering the challenges in monitoring standing crop, this level of variability is acceptable.

Question 19

> *Reply 3 Page 6-4. It is unclear why the effluent P versus P mass loading data from the North American Database for Wetlands is used (Figure 6-3). The environmental engineering field classifies hyacinth ponds as aquatic treatment systems, not wetlands. More importantly, the P removal mechanisms are highly different. In the project, the intent of the hyacinth ponds is to remove P by active removal of hyacinth biomass (harvesting). Wetlands do not typically function with highly active harvesting processes.*
>
> *For the high rates of P removal, the mass of hyacinth plants harvested (mass/surface area-day) must be high. An analogy can be drawn with suspended growth biological treatment systems, where process theory has been well developed. High specific growth rates of plant harvesting produce high specific growth rates. The volumetric processing rate has a maximum point at relatively lower mean cell residence times that are typically used in design, and is associated with higher effluent concentrations. In terms of an aquatic treatment system (hyacinth pond), it is proposed to use the term Mean Plant Residence Time (MPRT), which is the standing biomass in*

ponds divided by the biomass leaving the system per day.

MPRT = viable hyacinth mass in ponds/viable hyacinth mass harvested per day.

For steady state, the MPRT is the inverse of the specific growth rate, μ:

MPRT = 1/ μ

*Long MPRT is associated with low specific growth rates. Shorter MPRT result in higher specific growth rates, and higher areal removal rates up to a maximum areal P removal rate (**PR_{max}**) at $MPRT_{max}$. At MPRT less than $MPRT_{max}$ areal plant coverage, standing biomass, and areal P removal rates would decline. At MPRT greater than $MPRT_{max}$, areal plant coverage and standing biomass would increase, but areal P removal rates would decline. $MPRT_{max}$ and PR_{max} would depend on the limiting factors of solar insolation, temperature, macronutrients inclu*ding nitrogen, micronutrients and other factors such as predation.

REPLY 19

Regarding the use of the North American Database, we intended to show that there is a change point associated with autotrophic systems, whether they are wetlands or Managed Aquatic Plant Systems (MAPS) at which increased loading results in proportional increase in effluent concentrations. While the point is made that wetland systems (non-managed) rely upon different mechanisms for phosphorus removal, we need to note that as discussed in Sections 4 and 5, there are components of the MAPS systems, both WHS™ and ATS™, which rely upon the same mechanisms as passive wetlands—these being peat accretion, resulting either from tissue sloughing as in the WHS™, or precipitation phenomenon at high pH, which are associated with ATS™ (as well as the passive SAV and PSTA approaches). So there is some overlap.

We have as suggested concentrated our efforts on the harvesting aspect of the technology, which is modeled similarly to other biological systems, such as suspended growth systems. The discussion regarding growth rates and MPRT are presently employed, and refinements are being made to the models (see Section 5) to better represent specific behavior associated with the S-154 and LOW condition. However, by pushing loading, we can seek the point at which both harvesting/cultivation efforts, and other processes, e.g. precipitation are optimal in combination. This is a reasonable quest, to try to discover the change point for WHS™ and ATS™ systems.

Note of course, that because the harvesting component is such a major part of the MAPS technology, much higher P removal rates can be expected when compared to passive wetland systems. Another issue to consider is the time element. Passive wetland systems are called so because they do not rely upon continual harvesting of biomass. However, realistically, from a Newtonian perspective, either harvesting (sludge management) or system closure and abandonment will ultimately be required. While these demands are delayed because of available storage, making the passive wetland technology appear low-tech/low operational demand, they are inevitable, and need to be resolved economically and operationally by those who seriously contemplates their use in Water Resource Management Programs. This is analogous to the old aeration lagoon systems (e.g. Hinde). Eventually there is no storage space left, and the stabilized sludge mass needs removal.

INQUIRIES THROUGH Q5 REPORT

Question 1

Explain the negative ortho-P removals obtained during the Q4-Q5 operational period.

REPLY 1

For one week during Q5 (2/16/04), there was a measured gain in Ortho-P on effluent (-6.47% removal). This event is not considered unusual, as it would be expected that there would be fluctuations in both directions in organic and ortho phosphorus throughout the system as a result of normal biological dynamics, such as plant uptake, enzymatic activity related to alkaline phosphatase, and phosphodiesterases, as well as solely chemical reactions. The role of enzymes in the transformation of phosphorus within expansive biological systems is discussed in some detail by Debusk4 . It is not surprising therefore that on occasion the rate of hydrolysis of organic phosphorus, and the subsequent generation of ortho phosphorus could equal and even outpace uptake of ortho phosphorus. This was disclosed and discussed in some detail within the discussions revolving around Figures 2-55 through 2-58 of Section 2, Analysis of Phosphorus Reduction, of the Q5 report, in which ortho phosphorus changes are noted with organic phosphorus reductions down the course of the ATS™ floway. Note for example the figure from the Q5 report, in which organic and total phosphorus decrease down the floway, while ortho phosphorus remains constant (Figure 6.5).

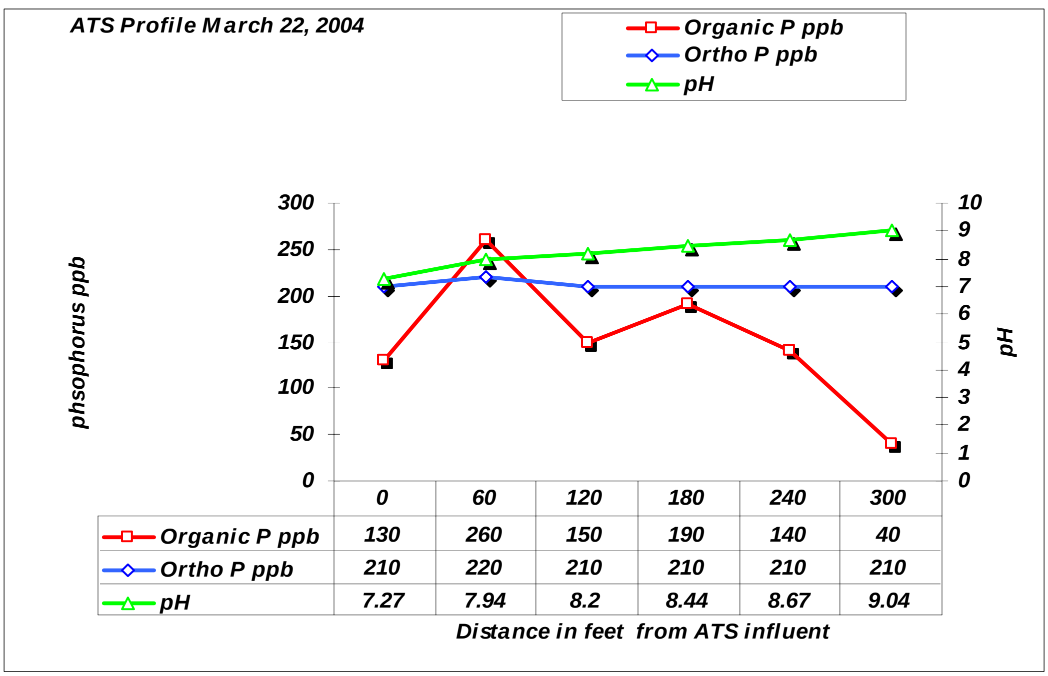


Figure 6.5: Phosphorus concentrations as related to distance from influent over the ATS™ floway.

The net gain in ortho phosphorus for a one-week sampling period would not necessarily be shown within the monthly averages reflected in Figures E-5 and E-6. While the overlap is somewhat blurred, the event of 2/16/04 is reflected in Figure E-7 of the Q4-Q5 report.

4 DB Environmental (2002) Demonstration of Submerged Aquatic Vegetation/Limerock Treatment Technology for Phosphorus Removal from Everglades Agricultural Area Waters: Follow-On Assessment prepared for the South Florida Water Management District and the Florida Department of Environmental Protection, West Palm Beach, Fl, USA.

Question 2

What factors contributed to an increase in effluent TN concentrations during the months of Jan and Feb 2004?

REPLY 2

It was recognized during the initial assessment of the L-62 water quality conditions, as discussed within the Preliminary Engineering Report as submitted to the District, that the N:P ratio was lower than what would be considered optimum for biological productivity, and that accordingly, nitrogen may need to be supplemented during the course of operations to permit adequate reduction of phosphorus—i.e. it was necessary to avoid a nitrogen limiting situation within the WHS™ and the ATS™ units. Consequently, nitrogen was supplemented during all quarters, both as Potassium Nitrate and as Urea. The intent was to add enough nitrogen to solicit optimal productivity, while still ensuring a net reduction of influent nitrogen loads. This is explained within Section 2 of the Q5 report. For the entire Q1 through Q5 period, the S-154 influent water contributed 4,687.80 lbs of nitrogen, while the system effluent contained 3,987,31 lbs of nitrogen, or a net removal of 14.94% (Table 6.4). During this same period, 3,941.80 lbs of nitrogen were supplemented. Therefore the total incoming nitrogen was 8,629.60 lbs, and the total removal was 4,642.29 lbs, representing a removal of 53.79%. During January and February, 2004 the amount of supplemented nitrogen exceeded the systems need to support optimal productivity, hence this excess resulted in a "bleed-through" into the effluent. This was recognized, and the system was adjusted by reducing the amount of nitrogen supplemented. Accordingly, the system returned to a net removal status.

Table 6.4. Summary of Nitrogen removal capacity of the WHS™-ATS™ system.

	Q1	Q2	Q3	Q4	Q5	Total	Removal lbs from L-62	Removal lbs from all sources
L-62 Influent lbs	749.38	729.45	830.97	1,018.40	1,359.60	4,687.80	700.49	4,642.29
Effluent lbs	545.00	528.43	628.48	1,148.40	1,137.00	3,987.31	14.94%	53.79%
Supplemented lbs	498.20	731.20	835.60	1,290.00	586.80	3,941.80		

Question 3

Organic P is shown as the difference between total P and ortho-P, which ignores the dissolved hydrolyzable phosphorus fraction in the filtered sample. Theoretically, organic P values would have been lower if this fraction is accounted for.

REPLY 3

In the beginning of this project the monitoring plan was reviewed with the District staff, and the extent of phosphorus fractionation discussed. During the course of operation, there arose an issue about the difference between filtered and unfiltered ortho-P, and some effort was made to compare these values. (Please review the correspondence related to the Audit conducted at the site.) There has not, however, ever been any discussion to try to segregate that fraction of phosphorus that is not ortho-P into other fractions, such as dissolved hydrolyzable phosphorus. In fact, Debusk[1], in his analysis, refers to hydrolysable phosphorus as "hydrolyzable organic phosphorus". In other words, hydrolyzable phosphorus is considered a component of the more inclusive category called organic phosphorus, and this organic phosphorus is the difference between total phosphorus and ortho-P. We agree that had the scope allowed, it would have been helpful to discriminate between hydrolysable and non-hydrolyzable organic phosphorus. This is however, in our opinion, beyond the negotiated scope of this effort. Please note that HydroMentia, at its own expense, did investigate the fate of organic phosphorus down the ATS™ floway, as noted in Reply 1, and therefore did provide some insight into the extent of hydrolysable organic phosphorus. Also note that the term "hydrolysable" in fact is not easily established. Apparently, the use of this term within this comment means the difference between total and ortho-phosphorus from a filtered sample (0.4 μm). However, DeBusk[1] found that 27% of the filter retained organic phosphorus was hydrolysable. In addition, the extent of vulnerability to hydrolysation was a function of the specific enzymes present, with phosphodiesterase (PDEase) being much more effective than Alkaline Phosphatase. To fractionate the "organic" compartment into these various hydrolysable segments of course is well beyond the scope of this project. (Note that other approaches, such as KCL-extractable P and NaOH-extractable P can also provide insight into the forms of phosphorus.) This information would be quite helpful however, and would be a worthwhile pursuit for any subsequent ATS™ related contracts.

Question 4

How is N:P ratio calculated? Is this molar or mass ratio?

REPLY 4

Note that the values reported in Tables ES-1.1 and ES- 1.2 are mean concentrations based on weekly data. The influent N:P ratios reported are calculated as the mass of nitrogen associated with the influent from L-62, without consideration of supplementation, divided by the mass of phosphorus associated with the influent from L-62, without consideration of supplementation. The N:P ratio is not presented within this text as a molar ratio, but as a mass ratio. Noted in the five attached tables are the weekly and quarterly average N:P ratios. The average values vary only slightly from those reported in Q5, with the exception of Q3, which in the report is given as 9.91:1, while that shown in the attached Q3 table is 6.89:1.. This should be considered a typographical error, and has been corrected within this report. The differences other than Q3 influent, are likely due to minor arithmetic issues, and are considered insignificant. The comparison of the values in the below tables, and those given in the Q5 report are as follows (Tables 6.5 and 6.6).:

Table 6.5: Comparison of tabular vs. text reported values for N:P ratios included in Reports 1 through 5.

	Influent N:P	*Effluent N:P*
Q1		
Report	4.30:1	23.25:1
Tables	4.32:1	23.13:1
Q2		
Report	5.56:1	29.98:1
Tables	5.56:1	29.98:1
Q3		
Report	9.91:1	25.45:1
Tables	6.89:1	26.17:1
Q4		
Report	14.20:1	29.13:1
Tables	14.69:1	28.98:1
Q5		
Report	6.93:1	13.61:1
Tables	7.26:1	13.72:1

Reported quarterly ratios are averages, not ratios of sums. The ratio of monthly sums is presented within the attached tables, and they do vary slightly from the averages. The implications regarding the system's dynamics are the same regardless of which value is used--that being that the facility results in an upward adjustment of N:P, which beneficially changes the environmental complexion for phytoplankton development away from a selective advantage for *cyanobacteria.*

Included also in the tables, which is not presented or discussed in the Q5 report, is the adjusted (after supplementation) ratio. As seen from the table, when nitrogen is supplemented, the N:P ratio increases, but it does not increase to levels as high as the effluent N:P. Therefore, the adjustment of N:P through the system is attributable to more than just the addition of supplemental nitrogen. (See COMMENT 9).

Table 6.6: Comparison of N:P ratios of Influent, Supplemented and Effluent nitrogen water quality for the period of record.

Q1 Week Ending	Influent TP load lbs	Effluent TP load lbs	Influent TN load lbs	Adjusted Influent TN load lbs	Effluent TN load lbs	N:P Ratio L-62 Influent	N:P Ratio Supplemented Influent	N:P Ratio Effluent
1/27/2003	7.86	2.31	30.63	45.01	30.48	3.90	5.73	13.20
2/3/2003	6.55	1.58	32.69	42.69	30.54	4.99	6.52	19.38
2/10/2003	6.74	1.27	34.47	49.78	33.17	5.11	7.39	26.15
2/17/2003	6.06	1.29	45.64	62.54	25.17	7.52	10.31	19.52
2/24/2003	8.35	1.10	46.16	71.86	28.95	5.53	8.60	26.36
3/3/2003	11.31	1.55	49.38	83.78	37.87	4.37	7.41	24.44
3/10/2003	14.22	1.96	49.96	85.46	41.44	3.51	6.01	21.19
3/17/2003	11.51	4.15	78.33	119.47	76.86	6.81	10.38	18.51
3/24/2003	15.26	2.23	34.51	74.81	29.86	2.26	4.90	13.38
3/31/2003	21.80	2.22	66.80	107.10	49.72	3.06	4.91	22.42
4/7/2003	17.70	2.43	75.10	120.80	19.82	4.24	6.83	8.16
4/14/2003	22.50	2.33	73.15	118.85	56.40	3.25	5.28	24.25
4/21/2003	13.22	1.32	54.10	107.00	42.87	4.09	8.09	32.53
4/28/2003	16.21	1.03	55.61	101.33	35.47	3.43	6.25	34.38
5/5/2003	18.72	0.85	51.84	104.74	36.66	2.77	5.60	43.13
total	198.03	27.60	778.39	1295.24	575.27	3.93	6.54	20.84
					Average	4.32	6.95	23.13

Q2 Week Ending	Influent TP load lbs	Effluent TP load lbs	Influent TN load lbs	Adjusted Influent TN load lbs	Effluent TN load lbs	N:P Ratio L-62 Influent	N:P Ratio Supplemented Influent	N:P Ratio Effluent
5/12/2003	16.25	0.51	45.66	98.56	27.92	2.81	6.07	54.55
5/19/2003	18.91	1.09	70.36	123.26	38.11	3.72	6.52	34.87
5/26/2003	8.88	0.97	55.37	108.27	39.36	6.24	12.19	40.54
6/2/2003	7.39	1.22	63.29	116.19	53.52	8.57	15.73	43.79
6/9/2003	10.12	0.90	55.61	108.51	32.06	5.49	10.72	35.71
6/16/2003	12.03	0.72	55.38	108.28	36.32	4.60	9.00	50.75
6/23/2003	9.81	1.46	57.25	115.55	40.41	5.84	11.78	27.69
6/30/2003	9.89	1.37	54.21	112.51	40.07	5.48	11.38	29.16
7/7/2003	14.90	2.13	67.05	124.05	44.50	4.50	8.33	20.93
7/14/2003	18.86	2.68	66.28	127.48	36.99	3.51	6.76	13.79
7/21/2003	10.84	6.02	54.74	115.94	54.79	5.05	10.70	9.11
7/28/2003	6.02	4.00	55.50	116.70	50.40	9.22	19.38	12.60
8/4/2003	4.81	1.80	34.68	95.88	29.32	7.20	19.92	16.30
total	148.70	24.87	735.37	1471.17	523.78	4.95	9.89	21.06
					Average	5.56	11.42	29.98

Table 6.6: Continued

Q3 Week Ending	Influent TP load lbs	Effluent TP load lbs	Influent TN load lbs	Adjusted Influent TN load lbs	Effluent TN load lbs	N:P Ratio L-62 Influent	N:P Ratio Supplemented Influent	N:P Ratio Effluent
8/11/2003	7.74	1.86	55.67	121.37	42.94	7.19	15.67	23.05
8/18/2003	11.13	1.48	54.64	120.34	41.52	4.91	10.81	28.08
8/25/2003	14.87	2.61	71.36	141.06	55.11	4.80	9.48	21.10
9/1/2003	8.33	0.85	178.94	243.24	26.16	21.49	29.22	30.60
9/8/2003	10.24	3.16	43.05	107.35	67.51	4.20	10.48	21.35
9/15/2003	9.34	1.89	45.03	110.73	41.59	4.82	11.85	22.02
9/22/2003	7.11	1.38	51.72	117.42	45.27	7.28	16.52	32.71
9/29/2003	5.95	2.06	39.84	105.54	40.75	6.69	17.73	19.78
10/6/2003	7.94	1.33	37.34	98.94	34.67	4.71	12.47	26.01
10/13/2003	14.67	1.98	64.35	125.95	59.42	4.39	8.58	30.05
10/20/2003	12.12	2.43	60.06	121.66	65.04	4.96	10.04	26.75
10/27/2003	9.95	1.66	62.52	124.12	46.11	6.28	12.47	27.81
11/3/2003	8.43	2.02	66.45	128.05	62.37	7.88	15.19	30.90
total	127.83	24.72	830.97	1665.77	628.48	6.50	13.03	25.42
					Average	6.89	13.89	26.17

Q4 Week Ending	Influent TP load lbs	Effluent TP load lbs	Influent TN load lbs	Adjusted Influent TN load lbs	Effluent TN load lbs	N:P Ratio L-62 Influent	N:P Ratio Supplemented Influent	N:P Ratio Effluent
11/10/2003	8.48	3.37	72.66	196.26	100.62	8.57	23.15	29.83
11/17/2003	12.33	2.72	94.97	221.37	70.51	7.70	17.95	25.88
11/24/2003	12.68	4.90	319.54	445.94	116.57	25.20	35.16	23.80
12/1/2003	5.98	3.74	151.72	272.62	107.51	25.36	45.57	28.77
12/8/2003	6.87	2.51	98.54	214.84	114.46	14.35	31.28	45.65
12/15/2003	5.22	3.48	59.78	176.08	79.36	11.45	33.72	22.80
12/22/2003	4.51	2.63	108.52	224.82	65.73	24.08	49.88	24.96
12/29/2003	6.55	2.64	71.57	187.87	107.24	10.92	28.67	40.69
1/5/2004	7.75	4.23	89.47	205.77	114.23	11.55	26.55	27.03
1/12/2004	6.62	4.01	75.34	126.34	93.67	11.38	19.08	23.36
1/19/2004	7.23	4.74	80.52	124.62	118.75	11.14	17.23	25.03
1/26/2004	5.59	3.99	81.34	125.44	119.46	14.54	22.42	29.93
total	89.82	42.96	1303.97	2521.97	1208.09	14.52	28.08	28.12
					Average	14.69	29.22	28.98

Q5 Week Ending	Influent TP load lbs	Effluent TP load lbs	Influent TN load lbs	Adjusted Influent TN load lbs	Effluent TN load lbs	N:P Ratio L-62 Influent	N:P Ratio Supplemented Influent	N:P Ratio Effluent
2/2/2004	6.93	4.30	90.10	134.20	122.16	13.01	19.38	28.43
2/9/2004	7.06	4.64	92.99	102.89	131.54	13.17	14.58	28.37
2/16/2004	5.88	4.13	74.60	80.90	70.69	12.69	13.77	17.14
2/23/2004	7.18	4.03	66.96	72.36	63.48	9.33	10.08	15.77
3/1/2004	7.36	3.68	83.70	89.10	79.52	11.37	12.11	21.62
3/8//2004	20.15	5.55	79.16	84.56	78.05	3.93	4.20	14.06
3/15/2004	19.19	8.35	52.24	57.64	72.07	2.72	3.00	8.63
3/22/2004	30.07	11.82	72.07	105.57	61.34	2.40	3.51	5.19
3/29/2004	22.36	9.24	106.81	135.31	85.18	4.78	6.05	9.22
4/5/2004	15.27	6.62	78.96	112.46	58.31	5.17	7.37	8.81
4/12/2004	9.79	3.42	47.24	80.74	35.16	4.83	8.25	10.28
4/19/2004	14.30	5.52	83.54	131.44	55.90	5.84	9.19	10.13
4/26/2004	10.92	4.51	70.91	118.81	43.73	6.50	10.88	9.70
5/3/2004	10.56	4.26	60.51	108.41	41.77	5.73	10.27	9.80
5/10/2004	8.79	4.78	63.00	110.90	26.89	7.17	12.62	5.63
5/17/2004	10.97	6.77	71.87	119.77	53.77	6.55	10.91	7.95
5/24/2004	12.51	4.41	88.63	136.53	73.68	7.08	10.91	16.70
5/31/2004	16.07	4.11	136.03	183.93	80.51	8.47	11.45	19.61
total	235.34	100.10	1419.30	1965.50	1233.77	6.03	8.35	12.33
					Average	7.26	9.92	13.72

Question 5

Whs provided nearly 73% of the system's phosphorus treatment for the first three quarters and only 59% for the last two quarters. Ats on the other hand, accounted for 27% and 41% of phosphorus removal for q1-q3 and q4-q5, respectively. Is this a direct result of operational changes implemented in q4-q5 to address the phosphorus load reduction goal? Also, why the disparity on whs removal rates in q4 and q5 (49% to 69%)?

REPLY 5

Because the relative size and hydraulic loading rates, as well as influent concentrations, fluctuated over this period, the comparison of percent removal contribution is somewhat more ambiguous than the variation in phosphorus areal removal rates for the two processes. Noted in the attached figure are the loading and removal rate trends from Q1-Q5 for phosphorus (Figure 6.6). Shown in the attached table is a summary of average phosphorus loading and removal rates for the Q1-Q5 period (Table 6.7). The following observations can be made in review of this information.

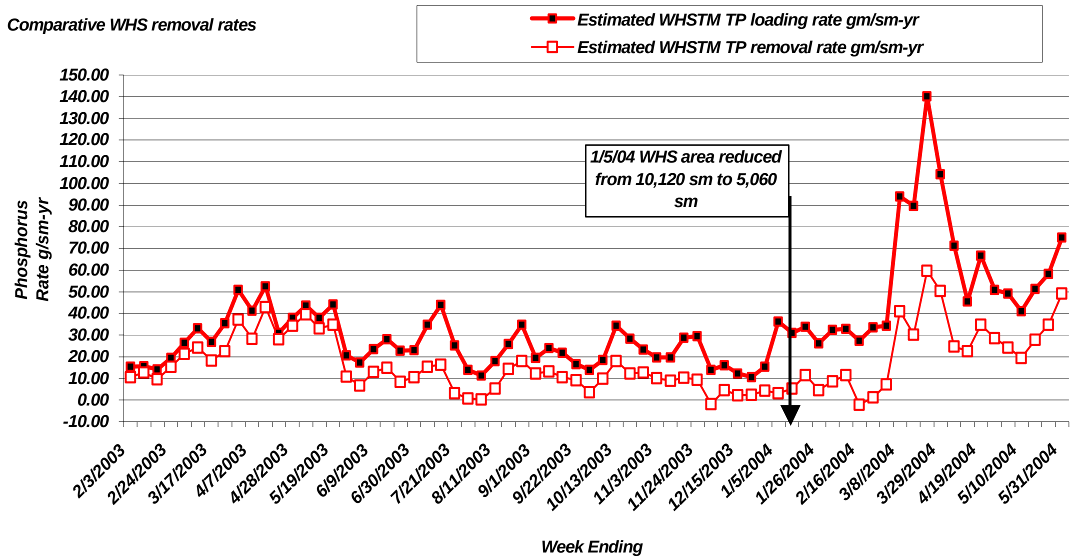
- Regarding WHS™ performance, it shows a significant drop in Q2, which is attributable somewhat to the event as discussed in the report related to the herbicide spraying. This was also a time when some management adjustments were being made, including the installation of pond booms to protect the crop from excessive densities. A more dramatic drop in WHS™ performance however, is noted in Q4. This is due to two factors—the drop in temperature, which reduces productivity, and a low influent total phosphorus concentration. As has been suggested, WHS™ systems perform better at higher nutrient concentrations. With the average influent total phosphorus for Q4 being only 176 ppb, the removal rate fell accordingly.

- During Q5 both influent total phosphorus and temperature increased and the WHS™ responded accordingly.

- The ATS™ performance has been rather consistent throughout the Q1-Q5 period, except for Q1, when pH adjustments were being made and the system continued start-up. When the hydraulic loading rate was increased in Q4, the ATS™ sustained comparatively high removal rates, even during cooler temperatures and lower total phosphorus influent concentrations. With the increased hydraulic loading rate, the recycling of effluent onto the ATS™ was discontinued, as was the addition of acid. This appeared to have a somewhat positive influence on the system. However, linear hydraulic loading rate (LHLR), which is the measure of flow volume per unit foot of ATS™ width at the headworks (surgers) was not increased, which may have restrained further enhancement of performance. The single stage ATS™ investigation, the review of which will be submitted as a separate document, includes a detailed review of the influence of LHLR on system performance.

- During Q5, there was considerable construction and moving of the ATS™ system, as the single stage floways were installed. This most likely impacted performance to some extent during Q5. Information will be forthcoming on Q6, and a more comprehensive modeling effort will be made to attempt to address the dynamics of the system over the operational period.

- Unlike the WHS™, the ATS™ does not appear to be as dramatically influenced by total phosphorus concentration.



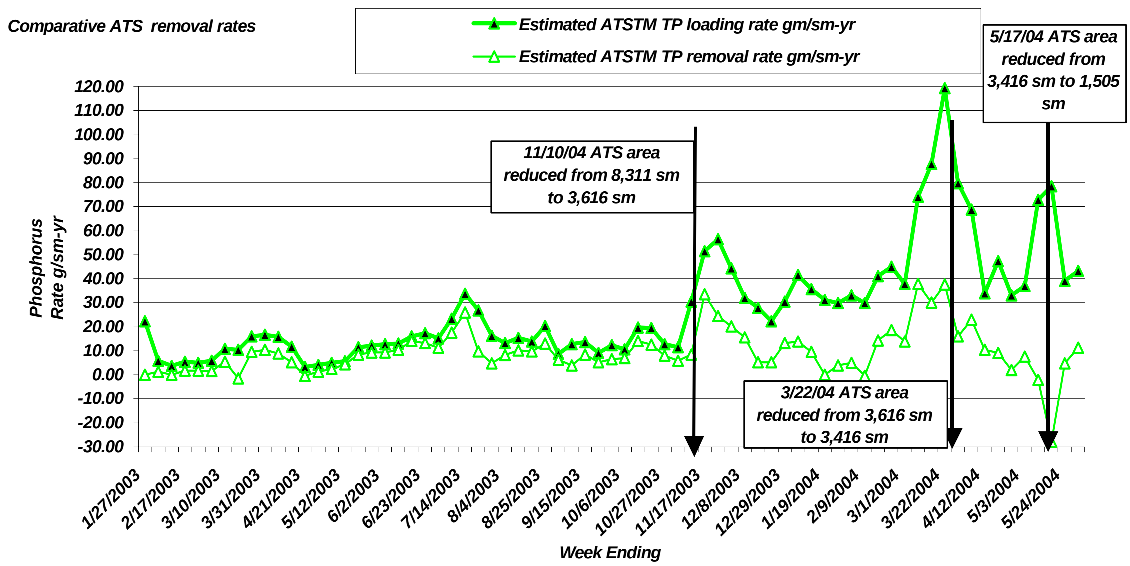


Figure 6.6: Comparison of TP loading and removal rates for the WHS™ and ATS™ processes for Q1-Q5.

Table 6.7: WHS™ and ATS™ Phosphorus loading and removal rates for Q1 through Q5.

	WHS Area sm	ATS Area sm	WHS™ TP loading rate gm/sm-yr	WHS™ TP removal rate gm/sm-yr	ATS™ TP loading rate gm/sm-yr	ATS™ TP removal rate gm/sm-yr	Average TP influent to WHS ppb	Average TP influent to ATS ppb
Q1	10,120	8,311	31.31	23.92	9.00	4.41	545	127
Q2	10,120	8,311	25.21	9.23	19.47	12.82	414	259
Q3	10,120	8,311	22.94	11.51	13.91	8.51	445	217
Q4	8,855	4,007	22.75	5.44	36.17	12.79	176	124
Q5	5,060	3,260	61.00	26.36	55.69	11.75	255	152
		Averages	32.64	15.29	26.85	10.06	367	176

Question 6

How did the increase in effluent flow (from heavy rainfall) during the third quarter impact the system's nutrient (N & P) removal efficiencies for that quarter?

REPLY 6

During Q3, there was a net gain inflow of 1.03 million gallons to the inflow of 36.31 million gallons, or a potential dilution factor of 2.9%. The influent total phosphorus for the Q3 was 127.8 lbs from L-62 at a concentration of 434 ppb and 0.59 lbs from rainfall (25 ppb). The effluent total phosphorus was 24.72 lbs at a concentration of 82 ppb. If the dilution from rainfall is taken into consideration the effluent would be 84 ppb. Other than the dilution influence, there is little evidence that the increase in effluent flow from heavy rainfall significantly impacted, either deleteriously or beneficially, the system's nutrient removal efficiencies during Q3.

Question 7

What is the theoretical basis for taking the average of TP and ortho-P concentrations for 24-hr composite and grab samples and using them to estimate ortho-P concentrations for a 6-day composite sample? There is some variability in TP concentrations for day 1-6 composite, 24-hr composite, and grab samples summarized in Table 2-8.

REPLY 7

During negotiations regarding sampling protocol, it was noted that taking a 7 day composite sample for ortho-P would exceed the holding time, and essentially invalidate or at least cast doubt upon the results regarding ortho-P. Instead, what was decided was to take an ortho-P sample on the last day—the 24-hour composite—and let that serve as an indicator of ortho-P concentration. However, applying the direct value of the 24-hour sample to the whole week required ignoring the fluctuations in the previous six-day period related to total phosphorus. In some cases for example, it might have meant setting an ortho-P value higher than the total phosphorus, which is scientifically incongruous. Instead, we chose to take the ratio of the averages of the 24-hour and grab ortho-P values to the 24-hour and grab total P to use as a set percentage of the weekly total P concentration, which was set as the estimated ortho-P concentration. Understanding that grab sampling is a less accurate method of quantifying nutrient concentrations than composite samples, this equation is an attempt to reduce some uncertainty by determining estimated ortho-P based on its fraction of the total P in two samples. This seems a reasonable approximation, but certainly not the only option.
Also, please see reply to Question 4 in Section 6 of Q4-Q5

Question 8

Why are TP concentrations in the ATS effluent higher compared to WHS effluent, from Feb 3 to March 17, 2003? Although differences may not be significant, what are the possible sources of TP released to the system?

REPLY 8

Note that the three values being compared within Table 2-9—WHS™ effluent and north and south ATS™ effluent-- are grab samples. Consequently, they do not accurately represent an extended profile of water quality. Those cases in which the ATS™ effluent total phosphorus values are equal or higher than the WHS™ effluent values are limited to the early weeks of Q1. During this period the ATS™ was in a start-up phase, effluent was being recycled to the ATS™, and we were attempting to bring the pH issue under control through addition of acid. After Q1, the system reached a more stable state. Regarding a source of phosphorus from the ATS™, it is conceivable that disturbed algae cells could lyse and release nutrients under certain stress conditions—such as extensive drydown or high pH. After Q1, there has been no real evidence of a net phosphorus release from the ATS™.

Question 9

> *Please state that the increase in N:P ratios for the effluent is a direct result of supplementing the system with nitrogen.*

REPLY 9

Please see REPLY 4. Note that while the supplementation of nitrogen to the influent increased the influent N:P ratio, this ratio was further increased within the effluent as a result of extensive phosphorus uptake, this uptake was partly supported through the nitrogen supplementation program.

Question 10

> *It will be interesting to see how the system's performance is influenced by changes in water chemistry (ph, conductivity, dissolved oxygen) over time. A simple correlation and/or regression analysis will be helpful in establishing some type of relationship between water quality parameters and concentrations of various nitrogen and phosphorus species in the effluent over time.*

REPLY 10

The relatively narrow range of variation in influent conductivity as observed within L-62 does not at first glance to be particularly influential on system performance. Dissolved oxygen levels in L-62 also do not appear to have any readily notable impact on system performance. Temperature of course, (both water and air temperature) does have influence on productivity, and hence performance. Alkalinity and pH as it relates to available carbon, does appear to have some influence on the second stage ATS™, as discussed within the report. Of course if there were wider variations in conductivity, particularly if levels approached toxic levels for water hyacinths, then some influence would be noted. The reported toxic level of conductivity for water hyacinths varies within the literature, but based upon HydroMentia's experience, when TDS approaches 3,000 mg/l production may show decline. The TDS within L-62 during the POR varied from 260 mg/l to 1,100 mg/l. The ATS™ has a greater tolerance range for conductivity, and in fact systems can and have been operated in full seawater (35 ppt salinity). The applicability of this analysis may be discussed in the upcoming PRT meeting.

QUESTION 11

> *The system was supplemented with 3.1 lbs of phosphorus during the first quarter. Was this accounted for in the calculation of phosphorus removal for that quarter?*

REPLY 11

The value of 3.1 lbs shown for phosphorus supplementation in Table 3-1 is incorrect. The 3.1 lbs is the entire amount of potassium phosphate added. The amount of phosphorus added was 0.44 pounds during the week of March 10, 2003. This was added during our effort to determine if productivity on the ATS™ could be stimulated by an increase in ortho-P. (The results were somewhat ambiguous). The 0.44 lbs supplemented phosphorus value was included in the phosphorus removal calculations for Q1. The error in the table will be corrected within Section 3.

Question 12

Negative nutrient removals indicate that the system is acting as a source of, rather than a sink for that nutrient. What are the negative total nitrogen removals observed in the 3rd, 4th and 5th quarters attributed to?

REPLY 12

In the comment, reference is made to "negative total nitrogen removals in the 3rd, 4th and 5th quarters". As shown in the attached tables, there actually are two dates in which negative total nitrogen removals are noted within the total system, these being the week ending 2/9/04 (-28.66 lbs) and 3/15/04 (-14.43 lbs). As noted in REPLY 2, this may be attributable to some extent to excessive supplementation. Other factors, including nitrogen fixation and excessive lysing or tissue sloughing could be responsible. As negative nitrogen removal is a rare occurrence, it might be considered anomalous, or an artifact of time lags or sampling or laboratory error.

In the report, note is made that on occasion, negative removals from L-62 influent (without supplementation) occur. This is simply a case in which supplemented nitrogen bled through the system. When the supplemented nitrogen is included in the influent load, there are, as noted, only two dates when nitrogen removal is negative.

Within the WHS™ system and the ATS™ systems individually, as noted in Figure 2-60 of the Q5 report, there are occasions in which nitrogen removal rates are reported as negative. This is particularly notable within the ATS™. As mentioned, these results are based upon grab samples, not composite samples, so they cannot be given the same degree of reliability as rates determined for the entire system. Nonetheless, some intermittent releases of nitrogen within the ATS™ could occur, as either lysed or sloughed cells, from nitrogen fixation, or possibly from immigration. It should be mentioned that nitrogen fixation within the ATS™ is not beyond possibility, but might be considered unlikely at the concentrations associated with this facility, as a selective advantage for nitrogen fixation usually is associated with nitrogen poor environments.

Table 6.8: Influent, supplemented, and effluent TN load and removal from the S-154 WHS™ - ATS™ system.

Q2	L-62 Influent TN load lbs	L-62 + Supplemented Nitogen Influent TN load lbs	Effluent TN load lbs	Removed TN lbs
5/12/2003	45.66	98.56	27.92	70.64
5/19/2003	70.36	123.26	38.11	85.14
5/26/2003	55.37	108.27	39.36	68.90
6/2/2003	63.29	116.19	53.52	62.67
6/9/2003	55.61	108.51	32.06	76.45
6/16/2003	55.38	108.28	36.32	71.96
6/23/2003	57.25	115.55	40.41	75.13
6/30/2003	54.21	112.51	40.07	72.44
7/7/2003	67.05	124.05	44.50	79.55
7/14/2003	66.28	127.48	36.99	90.48
7/21/2003	54.74	115.94	54.79	61.15
7/28/2003	55.50	116.70	50.40	66.30
8/4/2003	34.68	95.88	29.32	66.55

Table 6.8: Continued

Q3	L-62 Influent TN load lbs	L-62 + Supplemented Nitogen Influent TN load lbs	Effluent TN load lbs	Removed TN lbs
8/11/2003	55.67	121.37	42.94	78.42
8/18/2003	54.64	120.34	41.52	78.82
8/25/2003	71.36	141.06	55.11	85.94
9/1/2003	178.94	243.24	26.16	217.08
9/8/2003	43.05	107.35	67.51	39.84
9/15/2003	45.03	110.73	41.59	69.15
9/22/2003	51.72	117.42	45.27	72.15
9/29/2003	39.84	105.54	40.75	64.79
10/6/2003	37.34	98.94	34.67	64.27
10/13/2003	64.35	125.95	59.42	66.53
10/20/2003	60.06	121.66	65.04	56.62
10/27/2003	62.52	124.12	46.11	78.00
11/3/2003	66.45	128.05	62.37	65.68

Q4	L-62 Influent TN load lbs	L-62 + Supplemented Nitogen Influent TN load lbs	Effluent TN load lbs	Removed TN lbs
11/10/2003	72.66	196.26	100.62	95.64
11/17/2003	94.97	221.37	70.51	150.86
11/24/2003	319.54	445.94	116.57	329.38
12/1/2003	151.72	272.62	107.51	165.12
12/8/2003	98.54	214.84	114.46	100.38
12/15/2003	59.78	176.08	79.36	96.72
12/22/2003	108.52	224.82	65.73	159.09
12/29/2003	71.57	187.87	107.24	80.63
1/5/2004	89.47	205.77	114.23	91.54
1/12/2004	75.34	126.34	93.67	32.67
1/19/2004	80.52	124.62	118.75	5.87
1/26/2004	81.34	125.44	119.46	5.99

Question 13

P and N Budgets: (i) The various nutrient compartments depicted in the pie charts represent nutrient outputs from the system only. I suggest constructing a table showing all inputs to, and outputs from, the system to show net N and P exports (in lbs) for each quarter and for the entire period of record. (ii) What comprised ecological losses?

REPLY 13

The pie charts in this report have been replaced with 3-D bar charts in an attempt to better show nutrient inputs and outputs of the system. These values are also included in table format in Section 3. The issue of ecological losses is also addressed in Section 3. “The right side of Equation 8 represents ecological components, such as emigration, immigration, sediment regeneration, predation, and standing crop of consumer organisms, and is generally termed ecological losses (gains). For Equation 9, the right side includes the net between nitrogen fixation and denitrification as well as ecological losses (gains)."

Question 14

Average model projections for N and P removals are consistently lower than average actual except for effluent TP concentration. What are the implications of this prediction in terms of meeting a target TP concentration in the effluent?

REPLY 14

Implications of a conservative model projection is a level of conservatism within a final design**.** Please note that the HYADEM modelwas further tested within the final report, and its applicability is discussed in greater detail.

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SECTION 8. 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.