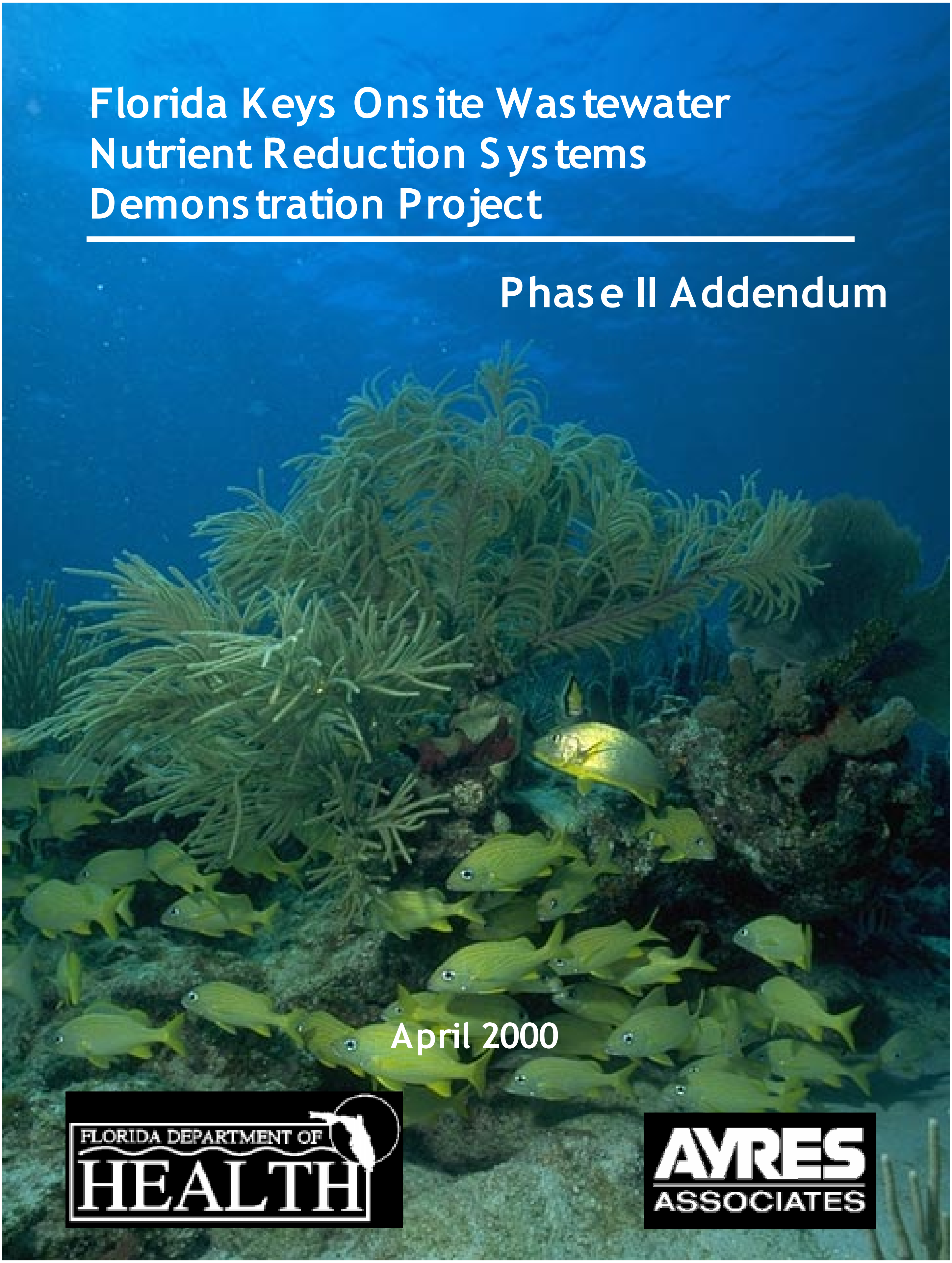
Florida Keys Onsite Wastewater Nutrient Reduction Systems Demonstration Project

Phase II Addendum



April 2000

FLORIDA DEPARTMENT OF HEALTH

AYRES ASSOCIATES

with funding from:

Florida Keys Onsite Wastewater Nutrient Reduction Systems Demonstration Project

Phase II Addendum

Submitted to:

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1.0 INTRODUCTION

In 1990, the United States Congress recognized the national and international significance of resource protection in the Florida Keys with the passage of The Florida Keys National Marine Sanctuary and Protection Act (Public Law 101-605). The sanctuary was established in part because negative impacts to the Florida Keys coral reef ecology and near-shore water quality had been documented in recent years. The Sanctuary consists of approximately 3,668 square miles of coastal and oceanic waters and the submerged land beneath them.

Under the sanctuary designation, the National Oceanic and Atmospheric Administration (NOAA) is charged with developing a comprehensive management plan and implementation regulations. The US Environmental Protection Agency (EPA), in conjunction with the State of Florida and NOAA, is responsible for development and implementation of a water quality protection program. The purpose of the Florida Keys Water Quality Protection Program (WQPP) is to:

> "...recommend priority corrective actions and compliance schedules addressing point and nonpoint sources of pollution to restore and maintain the chemical, physical, and biological integrity of the Sanctuary, including restoration and maintenance of a balanced, indigenous population of corals, shellfish, fish and wildlife, and recreational activities in and on the water" (Florida Keys National Marine Sanctuary and Protection Act, 1990).

1.1 Background

Domestic wastewater facilities were identified as the predominant source of anthropogenic nutrient loading to near-shore waters in the Florida Keys (US EPA, 1993). Wastewater sources were estimated to account for 79% and 56% of the combined wastewater/stormwater nitrogen and phosphorus loadings to Sanctuary waters, respectively. The overnutrification of nearshore waters is one of the major water quality concerns in the Sanctuary.

Onsite Wastewater Treatment Systems (OWTS) were targeted as one of the significant wastewater sources of nitrogen and phosphorus. Because of the significance of this source, the Water Quality Protection Program Report (US EPA, 1993) expressed the need for a demonstration of nutrient-reducing onsite wastewater treatment systems in the Florida Keys. The Florida Department of Health initiated the Florida Keys Onsite Wastewater Nutrient Reduction System (OWNRS) Demonstration Project in response to this need.

The results of the original OWNRS Demonstration Project are described in a report by Ayres Associates dated March 1998 and in Anderson et. al (1998). This report is prepared as an addendum to the original report and describes a second phase of OWNRS monitoring conducted from August 1998 to December 1999.

Details of the OWNRS design and monitoring, and test facility construction are not repeated here, but can be found in Ayres Associates (1998).

1.2 Summary of OWNRS - Phase I Results

The Florida Keys OWNRS Demonstration Project was designed to demonstrate the use and capability of alternative OWTS technologies for the Florida Keys. In Phase I several wastewater treatment processes, which provide a level of treatment superior to conventional OWTS, were tested to evaluate their potential to reduce organic, solids, and nutrient loading to near-shore waters of the Keys. An original goal of the project was to determine if the Florida advanced wastewater treatment (AWT) standards of 5/5/3/1 for effluent quality were feasible for OWTS. The AWT standards are defined as 5 milligrams per liter (mg/L) for Carbonaceous Biochemical Oxygen Demand (CBOD) and Total Suspended Solids (TSS), 3 mg/L for Total Nitrogen (TN), and 1 mg/L for Total Phosphorus (TP).

The project was conducted at a central testing facility (CTF) designed and constructed by Ayres Associates at the Big Pine Key Road Prison. The wastewater influent source for the CTF is obtained from the Big Pine Key Road Prison lift station prior to discharge into the prison's wastewater treatment plant (WWTP). Approximately one-third of the WWTPs influent is routed to the CTF influent mixing tank (IMT) prior to wastewater loading (dosing) of the OWNRS treatment systems.

The CTF on Big Pine Key was designed to allow comparative evaluations of numerous onsite wastewater treatment processes simultaneously, under controlled conditions, with a common wastewater source. The CTF allowed accurate monitoring of influent wastewater flows and the capability for flow-composited effluent sampling to determine treatment performance. A 200-gallon per day (gpd) wastewater flow was used for testing in Phase I. In addition to treatment performance, the operation, maintenance, and costs associated with each system were monitored over a one-year test period.

Based on the evaluation conducted during Phase I of the OWNRS Project, the following conclusions were drawn (Ayres Associates, 1998):

- AWT effluent standards for $CBOD_5$, TSS, and TP can be met consistently with the engineered media SDI system or by combining other of the systems/processes evaluated;

- TN reductions of >70% are achievable by biological nitrification/denitrification systems and could be increased with process optimization and/or supplemental carbon addition;

- A combination of various unit processes evaluated would achieve treatment performance by onsite wastewater systems, which approached AWT effluent standards. A biological treatment system designed for nitrification/denitrification (>70% TN reduction) that discharges to an engineered media SDI bed should consistently meet the AWT standards for $CBOD_5$, TSS, and TP, and reduce TN by over 85 percent. With process optimization and/or supplemental carbon addition, such a system should produce effluent close to the AWT nitrogen standard, as discharged from the SDI bed.

- Construction and operation costs of OWNRS will be considerably greater than conventional OWTS. Estimated total annual costs for the OWNRS evaluated, including effluent disposal and phosphorus removal by an engineered media SDI system, ranged from $1,730 to $2,841 per year. In comparison, annual cost for a conventional mounded OWTS in the Keys has been estimated at approximately $600 per year (Ayres Associates, 1998).

1.3 Objectives and Scope of Phase II

The key objective of Phase II of the Florida Keys OWNRS Demonstration Project was to study the performance of the alternative OWTS at the Central Test Facility over a longer term than the original 1-year study. The objectives of this phase include the following:

- Determination of performance efficiency of the treatment systems for a higher wastewater flow (200 to 320 gpd).
- Improvement of nutrient removal efficiency through process modifications and optimization.
- Continued monitoring of treatment performance, including collection of quarterly influent and effluent water samples from the five treatment systems to obtain additional analytical data required for long-term evaluation of the systems.
- Determination of O&M needs of the treatment systems over a longer term of operation.

2.0 PHASE II PROCESS MODIFICATIONS

In this section brief descriptions of the treatment systems studied are given. For each system the original design details (Phase I) are provide. The systems that underwent process modifications in Phase II are also identified and the details of the modifications are provided. Complete descriptions of the CTF operations, the five treatment systems and the process schematics are provided in the Phase I Final Report (Ayres Associates, 1998).

The primary modification affecting all systems during phase II was the increase of wastewater flow from 200 gallons per day to 320 gallons per day. This was accomplished by increasing the dose volume to the systems from 5 gallons to 8 gallons per dose. The dosing schedule remained the same as Phase I.

2.1 Process Systems

2.1.1 Process System 1-Recirculating Sand Filter/Anoxic Biofilter/Subsurface Drip Irrigation

Process Description - System 1 consists of a septic tank (ST-1) followed by a recirculating sand filter (RSF) and then an anoxic bio-filter (ABF). Effluent from the system is discharged to an unlined drip irrigation bed. Treatment occurs through digestion and settling in the septic tank and physical, chemical, and attached growth aerobic biological processes in the RSF. Adsorption by the RSF media removes limited quantities of phosphorus. The nitrified RSF effluent is mixed with anoxic septic tank effluent in the recirculation chamber (RC) to encourage denitrification. The effluent also undergoes nutrient reduction by plant uptake in the drip irrigation bed as well as by adsorption on the drip field media. Additional details of the system are found in Ayres Associates (1998).

The unlined drip irrigation bed utilizes a subsurface drip irrigation (SDI) system for effluent distribution to the sod root zone. The SDI consists of fifteen 5/8-inch drip irrigation lines spaced at 4-inch centers. The effluent is discharged via pressure emitters spaced every two feet within the lines. Each emitter discharges at a rate of 0.6 gallons per hour (gph). Three treatment media are evaluated in this treatment unit: 1) locally available sand; 2) an expanded clay aggregate from Norway, commercially known as LECA™; and 3) crushed brick material from Cherokee-Sanford Brick Company, Sanford, NC. Collection pans are placed at the bottom of each bed. A peristaltic pump is used during sampling to pull water quality samples from each collection pan. Grab samples are collected from each pan and labeled as USAND, ULECA, and UBRICK.

System Operation Performance/Observations - Operational problems encountered include apparent fouling of the drip irrigation lines, which was noted during the November 1999 operation and maintenance visit. The lines were flushed and put back into service.

System Modifications - In January 1999 the sand media in the RSF was replaced with 2-4 mm LECA media. Also, two lines were routed from the recirculation chamber (RC). One line was routed to septic tank 1 (ST-1) and the other one to the anoxic biofilter (ABF). These lines were installed in an attempt to provide enhanced denitrification within ST-1 and add BOD as a carbon source for additional denitrification in the ABF. Also, two stainless steel suction lysimeters were installed in the unlined sand and unlined crushed brick beds in an effort to improve sample collection from these locations.

2.1.2 Process System 2 - Septic Tank/Lined Drip Irrigation Bed

Process Description - This system utilizes a relatively passive technology consisting of a septic tank (ST-2) followed by a lined drip irrigation bed. The STE is distributed to the root zone via pressurized drip emitters in the same manner as the unlined bed described above. STE, which is not discharged, is recycled back to the influent side of ST-2. Reduction of nutrients and other parameters is accomplished by preliminary digestion and settling in the septic tank with additional physical, chemical, and biological treatment processes occurring in the lined irrigation field and by plant uptake. Under proper conditions, the effluent undergoes nitrification in the upper unsaturated (aerobic) portion of the drip bed and denitrification in the saturated (anaerobic) lower portion of the drip bed.

The lined bed is constructed in a similar manner and with the same treatment media as the unlined bed. The exception is that each treatment media is hydraulically separated from each other and the groundwater by an impermeable liner. The final effluent from the lined beds is collected by an underdrain system, which flows, by gravity into three effluent chambers for sampling and flow monitoring.

System Operation Performance/Observations - One operational problem was encountered during the course of the study. The rubber liner associated with the pinch valve controlling the dose pots ruptured on approximately November 30, 1999. This resulted in a decrease in doses for approximately one day. The valve was replaced with the valve from Process System 4, which had been taken out of service due to mechanical failure.

System Modifications - In January 1999, the original drip irrigation system was replaced with a system by Geoflow™. The design details of the Geoflow™ system include the following:

- Eleven, 33 foot long, subsurface drip irrigation lines.
- Drip line spacing = 0.5 ft.
- Total number of emitters = 681.
- Emitter flow rate = 0.5 gallons per hour.
- 24 doses per day at approximately 2 minutes per dose.

Additionally, the system is equipped with flush valves to flush the lines and filters on a scheduled basis.

The LECA Material in the lined drip irrigation bed was replaced with Filterlite-P, an advanced form of LECA. The old sod was removed and new sod was placed in the lined drip irrigation bed. In July 1999, a trickling filter was installed in association with the ST-2 to aid in denitrification.

2.1.3 Process System 3 - Bio-Microbics FAST™/Anoxic Bio-Filter

Process Description - The principal treatment unit in this system is a proprietary unit known as the Bio-Microbics FAST™ aerobic unit. This unit utilizes fixed-film activated sludge (FAS) treatment, which uses a combination of suspended growth and attached growth aerobic biological processes. The aeration process also provides circulation of wastewater to increase contact with aerobic bacteria. Also, anaerobic zones within the FAST chamber result in denitrification. This system provides a nitrified effluent prior to discharge.

The FAST treatment tank is separated into two chambers. The first chamber receives dosed influent and provides primary treatment. Wastewater overflows via a 6-inch diameter orifice in the partition wall to a second chamber where secondary treatment is provided by the FAST unit. A blower mounted outside on top of the treatment tank provides the air source for the FAST aeration. Treated wastewater then flows by gravity into an effluent chamber where it is pumped to an ABF treatment unit.

System Operation Performance/Observations - No operational problems have been noted during the test period.

System Modifications

In May 1998, the FAST system was modified replacing the original mushroom shaped top of the unit with a low profile top, which can be buried to provide a more aesthetic appearance. Additionally, during the course of the operation the timing sequence for aeration was modified three times. The modified timing sequences were:

- Initial timing sequence of 4.5 hours of aeration followed by 1.5 hours off.
- June 1999: 1.0 hour aeration followed by 1.0 hour off.
- August 1999: 1.0 hour of aeration followed by 1.5 hours off.

2.1.4 Process System 4 - Advanced Environmental Systems BESTEP

Process Description - This system consists of a proprietary treatment unit known as the AES BESTEP-IDEA™ system, an aerobic/anaerobic, suspended growth biological treatment process which operates as a continuous feed cyclic reactor (CFCR). The process operates similar to a sequencing batch reactor (SBR) but is unique in that it allows continuous flow while using only one process tank. Aeration to the system is cyclical, which causes alternating aerobic and anoxic conditions. This results in nitrification followed by denitrification for nitrogen removal and, promotes uptake of phosphorus by the activated sludge biomass.

System Operation Performance/Observations - This system operated on a limited basis during the Phase II test period. Problems encountered with this system included erratic controls and failure of the system to properly decant the wastewater during the settling period.

System Modifications - No modifications were made to this system during Phase II of the project. This unit was dropped from testing due to lack of manufacturer support for single home systems.

2.1.5 Process System 5 - Klargester Biodisc/ABF

Process Description - This system consists of a proprietary treatment unit known as the Klargester Biodisc™, which is a rotating biological contactor (RBC), followed by an anoxic bio-filter (ABF). The RBC is an attached growth, aerobic biological treatment process that provides BOD and suspended solids removal and limited nitrogen removal via an internal cycle of nitrified effluent to the primary clarifier for denitrification. It produces nitrified effluent, which is discharged to an ABF for additional nitrogen removal.

Influent from the dose pot is directed down into a primary settling tank. The wastewater flows up into the secondary treatment area where the RBC is located. The RBC is divided into three media disk banks with eight disks in each bank. As the wastewater flows through the RBC it empties into a final settling tank which discharges by gravity into the ABF. A pump placed the in final settling tank recycles sludge to the primary tank every hour for thirty seconds, at a flow rate of 10 gpm. The RBC effluent flows through three stages of submerged plastic filter media in the ABF and then into a sump area.

System Operation Performance/Observations - Problems encountered with this system were associated with the modifications described below. The primary problem was caused by the motor which became dislodged from the rotating disk. Also, the nylon bushings associated with rotating disk required replacement during Phase II of the test.

System Modifications - Modifications were made to this system to allow the second stage of the RBC rotor to receive flow from the first stage at a fixed rate and provide a stable organic and hydraulic load to the treatment process. This modification was achieved by modifying the opening between the first and the second stage of the unit.

The modifications also incorporated a carbon feed arrangement whereby a small amount of wastewater containing BOD was collected from the front of the RBC rotor and fed to the submerged anoxic reactor of the denitrification module. This organic carbon, in the form of BOD provides nutrient to the bacteria performing the denitrification.

2.1.6 Supplemental Carbon Feed Process

Process Description - This system consists of a proprietary treatment unit known as the "NiteLess" denitrification system. The technology of this system is based on automatic addition of dry carbon and freeze dried denitrifying bacteria. Delivery of the product is via a closed product hopper with opening and closing valves, a vibrator, drop tube drier, a hopper desiccant and a master timer. The unit is adjustable from one to fifteen dosing cycles per day and the volume of product dispensed may be increased or decreased based on system requirements. The "Niteless" system was added to the ABF located downstream from the FAST unit to provide additional denitrification of effluent received from the FAST. These samples were labeled FAS-ABF.

2.2 Drip Irrigation Field Core Sampling

Midway through the Phase II monitoring it was determined that core sampling of the drip irrigation media would be required to more adequately estimate the phosphorus removal capacity and life expectancy of these systems. Therefore, at the request of the Florida Department of Health (FDOH), core sampling of the crushed brick media drip bed was arranged in exchange for one quarterly water quality sampling event.

On April 22, 1999, four core samples were collected from the crushed brick media via soil auger and sampling tubes. The media samples were collected at 2-inch intervals from the surface to 22 inches below the media surface. These samples were analyzed for phosphorus content to determine the depth of phosphorus saturation into the bed, and thus estimate system life.

3.0 TREATMENT PERFORMANCE RESULTS

3.1 Influent Wastewater Hydraulic Loading

The system startup for Phase II of the OWNRS project central test facility was August 19, 1998 and the system ran until Hurricane Georges hit the area on September 25, 1998. The system was not operational from September 25, 1998 to October 19, 1998. On October 19, 1998 the system was restarted on a limited basis while repairs were being made. Phase II monitoring continued until December 1999. The actual operation period is estimated at 324 days because of system downtime. The downtime was due to hurricane damage repairs, routine system operation and maintenance, system and process adjustments, and various equipment malfunctions.

The hydraulic loading to the process streams was determined using the float counter inside each dose pot. The total numbers of doses were divided by the number of days the system was in operation. Based on this method, the average actual daily loading to each treatment process stream was 307 gpd. The average hydraulic loading to the systems was thus slightly less than the design flow of 320 gpd mainly due to system down time.

3.2 Influent Wastewater Quality Results

Twenty-four hour flow composited samples were collected from the influent mix tank (IMT) during August and September 1998 and then from December 1998 through December 1999. Samples were analyzed according to Standard Methods (APHA, 1992) for the following parameters: biochemical oxygen demand (BOD_5), carbonaceous BOD_5 ($CBOD_5$), total suspended solids (TSS), total Kjeldahl Nitrogen (TKN), nitrate + nitrite nitrogen (NO_2NO_3-N), ammonia nitrogen (NH_4-N), orthophosphate (PO_4), and total phosphorous (TP). Results of the water quality analyses for the influent samples are provided in Table 3-1. The detailed analytical data are provided in Appendix A.

Influent wastewater quality was within the range of that reported in the literature for untreated domestic wastewater (Metcalf and Eddy, 1991) with mean $CBOD_5$, TSS, TN, and TP values of 109, 92, 48, and 8.7 mg/L, respectively. Significant variations about these mean values were measured over the various sampling events, but this is typical of domestic wastewater from individual homes or small groups of homes.

In comparison to Phase I monitoring, influent values in Phase II were lower for CBOD and TSS, higher for TN and similar for TP. Of key importance to this study were the TN values. Average Phase II influent TN was approximately 10 mg/L higher than Phase I value. This in combination with the 60% increase in flow resulted in a much more difficult test for nitrogen removal for the OWNRS studied in Phase II.

Table 3-1. Summary of Influent (IMT) Water Quality Data, Phase II

Parameter (mg/L)	No. of Samples	Mean	Standard Deviation	Range	
				min	max
BOD_5	12	135.50	30.62	56.00	160.00
$CBOD_5$	13	109.62	36.58	39.00	190.00
TSS	13	92.38	26.78	48.00	133.00
TKN	13	47.92	12.15	29.00	66.00
NO_2-NO_3 N	13	0.06	0.10	0.01	0.28
TN	13	47.98	12.12	29.01	66.01
TP	13	8.72	2.01	5.70	12.00
NH_4	9	38.11	11.23	22.00	53.00

(1) mg/L = milligrams per liter

3.3 Temperature, Precipitation, Evapotranspiration Monitoring

A data logging weather station installed at the CTF collected temperature and rainfall data every one-half hour and stored them internally for downloading into a portable computer. Due to Hurricane Georges, weather data at the CTF for October, November, and December 1998 was not available. Also, due to electrical outages at the CTF, weather data for the months of August and September 1999 was unavailable. Supplemental weather data could not be obtained from the U.S. Fish and Wildlife Service, National Key Deer Refuge, Big Pine Key, due to maintenance of their system. The temperature and precipitation data showed the typical seasonal trends in South Florida with relatively mild, dry winters, and warm, wet summers. The majority of the rainfall occurred during June through August 1999. October 1999 was unusually wet with 14.58 inches of rainfall recorded due to Hurricane Irene and was the wettest month during the study period. The driest month recorded was January 1999 with 0.73 inches of rainfall. The warmest month was August 1998 with an average monthly temperature of 87.92° Fahrenheit (F). The coldest month was March 1999, with an average monthly temperature of 73.33 °F. Rainfall and temperature data is presented in Appendix B

Evapotranspiration (ET) was estimated at the CTF utilizing the ETgage™. The ETgage™ was installed at the north end of the lined SDI beds and readings began in December 1998. The time period from July 29, 1999, to September 1, 1999 indicated the highest ET rate of 0.1226 inches per day. The time period from January 18, 1999 to January 27, 1999 indicated the lowest ET rate of 0.0689 inches per day. The results of the ETgage™ are summarized in Table 3-2.

Table 3-2. Measured Evapotranspiration Rates (inches/day).

Period	Days in Period	ET for Period (inches)	Ave. ET/day (inches)
12/17/98 to 1/18/99	32.00	2.64	0.0825
1/18/99 to 1/27/99	9.00	0.62	0.0689
1/27/99 to 2/17/99	21.00	2.76	0.1314
2/17/99 to 3/22/99	33.00	3.9	0.1182
3/22/99 to 3/23/99	1.00	0.11	0.1100
3/23/99 to 4/22/99	30.00	4.1	0.1367
4/22/99 to 5/26/99	34.00	2.9	0.0853
6/23/99 to 7/29/99	36.00	4.23	0.1175
7/29/99 to 9/1/99	34.00	4.17	0.1226
9/1/99 to 9/29/99	28.00	2.76	0.0986
9/29/99 to10/28/99	29.00	2.13	0.0734
10/28/99 to 12/2/99	35.00	4.22	0.1206
12/2/99 to 12/17/99	15.00	1.27	0.0847
Average Daily ET/Year			0.1039
Min			0.0689
Max			0.1367
St. Dev.			0.0228

3.4 Wastewater Treatment Performance

The performance of the various treatment units was compared using the reductions in $CBOD_5$, TSS, TN, and TP. Results of the water quality analyses for the influent and six process stream effluents are provided in Table 3-3. Table 3-4 provides the effluent water quality results obtained during Phase I of the study.

For the lined bed SDI system (Process Stream 2), the results of the LECA ™ (LLECA) and crushed brick media (LBRICK) are reported. As a benchmark, the treatment performance of the various units was compared to the current standards in the Florida Keys of (10/10/10/1 mg/L monthly average for $CBOD_5$, TSS, TN, and TP, respectively).

3.4.1 $CBOD_5$ and TSS Reductions

The mean influent $CBOD_5$ concentration of 109.62 mg/L was reduced below the current Florida Keys effluent standard of 10 mg/L by all systems. The mean effluent $CBOD_5$ concentrations ranged from 1.0 mg/L for Process Stream 1 (RSF-ABF) to 1.24 mg/L for Process Stream 3 (FAS). It is to be noted that influent $CBOD_5$ concentrations during Phase II indicated a reduction in the mean influent concentration when compared to Phase I values, but due to the increase in flow, the effective $CBOD_5$ loading to the systems were higher in Phase II. The performance of the systems in removing $CBOD_5$, however, was found to be equivalent (or better) under increased loading conditions.

Figure 3-1 shows the mean ± the standard deviation for the $CBOD_5$ results by treatment unit, and gives an indication of the variability of $CBOD_5$ treatment performance.

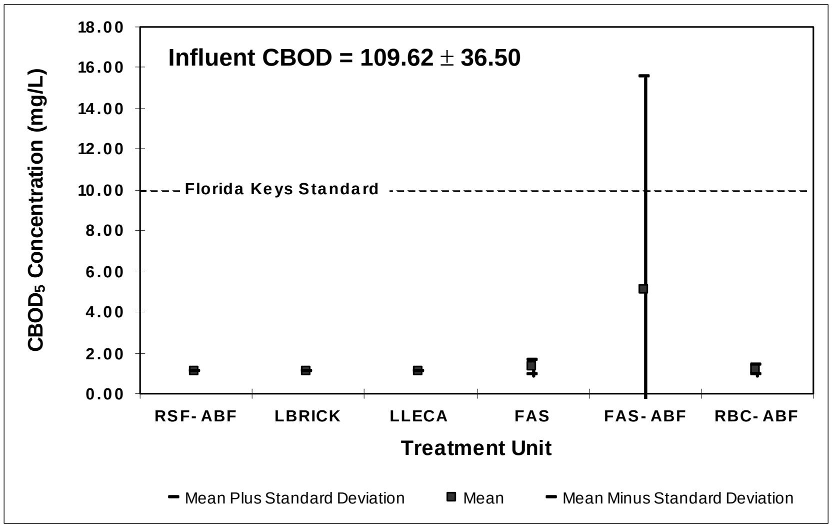

Figure 3-1. Effluent $CBOD_5$ Concentrations (Mean ± Std. Dev.)

Total suspended solids (TSS) were removed effectively below 10 mg/L by the RSF-ABF, LBRICK, LLECA™ and FAST™. Mean influent concentration of 92.38 mg/L was reduced to 1.29, 1.50, 5.00, and 3.85 mg/L, respectively by these systems. Mean TSS effluent concentrations in the RBC-ABF were 14.00 mg/L, which may be attributed to the carbon-feed arrangement to the ABF. Influent TSS results during Phase II indicated a reduction in the mean influent concentration when compared to Phase I.

The TSS removal efficiency in Phase II was found to be comparible with the Phase I results. Figure 3-2 shows the mean ± the standard deviation for TSS.

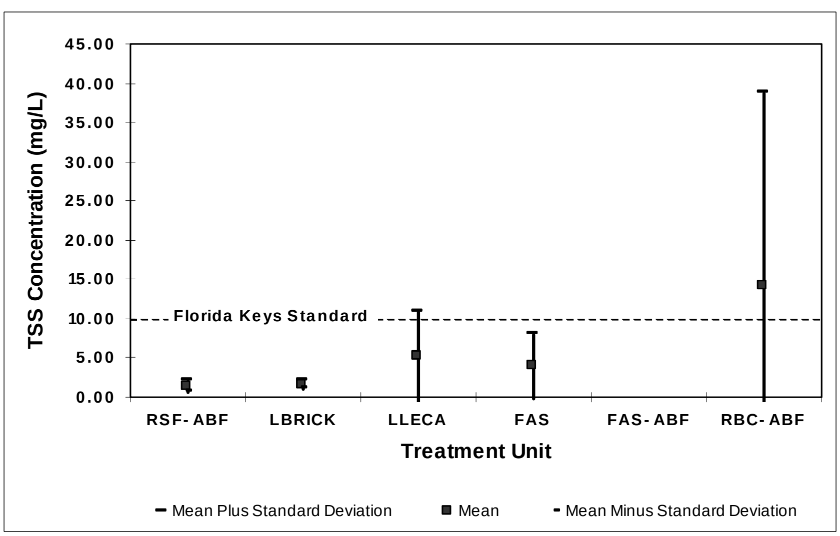

Figure 3-2. Effluent TSS Concentrations (Mean ± Std. Dev.)

Table 3-3. Summary of Effluent Water Quality Data, Phase II

Parameter	Statistic	Influent (IMT)	Process Stream 1 (RSF-ABF)	Process Stream 2 (LBRICK)	Process Stream 2 (LLECA)	Process Stream 3 (FAS)	Process Stream 3 (FAS-ABF)	Process Stream 5 (RBC-ABF)
BOD	Mean	135.50				3.73		
	Std. Dev.	30.62				1.18		
	Min	56.00				1.80		
	Max	160.00				5.60		
	n	12.00				8.00		
CBOD	Mean	109.62	1.00	1.00	1.00	1.24	5.02	1.10
	Std. Dev.	36.58	0.00	0.00	0.00	0.36	10.43	0.20
	Min	39.00	1.00	1.00	1.00	1.00	1.00	1.00
	Max	190.00	1.00	1.00	1.00	2.00	36.00	1.40
	n	13.00	8.00	4.00	6.00	14.00	11	4.00
TSS	Mean	92.38	1.29	1.50	5.00	3.85		14.00
	Std. Dev.	26.78	0.76	0.58	5.79	4.10		24.67
	Min	48.00	1.00	1.00	1.00	1.00		1.00
	Max	133.00	3.00	2.00	15.00	16.00		51.00
	n	13.00	7.00	4.00	5.00	13.00		4.00
TKN	Mean	47.92	0.48	0.79	0.92	1.16	1.30	1.90
	Std. Dev.	12.15	0.26	0.22	0.86	0.40	0.68	0.72
	Min	29.00	0.05	0.60	0.18	0.35	0.60	1.10
	Max	66.00	0.86	1.10	2.60	2.00	2.90	2.60
	n	13.00	8.00	4.00	6.00	14.00	12	4.00
NO2-NO3 N	Mean	0.06	25.75	30.50	28.17	10.34	5.79	13.00
	Std. Dev.	0.10	3.92	7.05	5.85	5.15	4.12	3.46
	Min	0.01	20.00	24.00	21.00	2.40	0.01	8.00
	Max	0.28	33.00	38.00	35.00	23.00	11.00	16.00
	n	13.00	8.00	4.00	6.00	14.00	12	4.00
TN	Mean	47.98	26.23	31.29	29.09	11.51	7.09	14.90
	Std. Dev.	12.12	3.79	6.93	5.79	5.34	3.55	3.88
	Min	29.01	20.45	25.10	21.51	2.75	2.31	9.50
	Max	66.01	33.05	38.75	35.69	25.00	11.60	18.60
	n	13.00	8.00	4.00	6.00	14.00	12	4.00
TP	Mean	8.72	1.46	2.65	0.53	6.62		6.80
	Std. Dev.	2.01	0.42	0.66	0.31	0.85		1.20
	Min	5.70	0.96	1.80	0.09	5.70		6.10
	Max	12.00	2.20	3.30	0.99	8.60		8.60
	n	13.00	6.00	4.00	10.00	13.00		4.00

Table 3-4. Summary of Effluent Water Quality Data, Phase I

Parameter	Statistic	Influent (IMT)	Process Stream 1 (RSF-ABF)	Process Stream 2 (LBRICK)	Process Stream 3 (FAS)	Process Stream 4 (CFCR)	Process Stream 5 (RBC-ABF)
BOD_5 (mg/L)	mean	170.90	2.18	3.98	5.58	4.16	2.42
	Std. Dev.	73.85	2.53	6.36	3.90	5.45	1.38
	min	62.00	1.00	1.00	1.00	1.00	1.00
	max	299.00	9.70	21.30	14.00	17.20	5.00
	n	10	12	11	11	8	11
$CBOD_5$ (mg/L)	mean	137.80	1.50	2.81	2.63	3.19	1.68
	Std. Dev.	60.13	0.90	4.04	3.15	5.18	1.24
	min	59.00	1.00	1.00	1.00	1.00	1.00
	max	220.00	4.00	14.40	9.01	15.90	5.00
	n	10	12	11	11	8	11
TSS (mg/L)	mean	117.50	2.25	4.09	4.63	6.85	5.75
	Std. Dev.	92.09	1.76	3.83	3.93	6.62	4.47
	min	17.00	1.00	1.00	1.00	2.00	1.00
	max	345.00	6.00	11.00	14.00	20.00	16.00
	n	12	12	11	12	10	12
TKN (mg/L)	mean	38.42	1.01	1.75	1.55	1.16	2.75
	Std. Dev.	10.67	1.44	2.10	0.82	0.52	2.62
	min	19.20	0.26	0.34	0.49	0.56	0.42
	max	62.50	5.30	8.19	3.40	2.20	7.40
	n	12	11	12	12	9	11
NO_2NO_3-N (mg/L)	mean	0.03	21.09	19.27	9.42	14.30	9.77
	Std. Dev.	0.02	6.76	10.09	4.06	6.49	3.69
	min	0.01	14.00	1.60	3.90	2.54	3.60
	max	0.05	35.20	36.60	19.70	23.00	17.00
	n	10	11	11	12	9	11
TN (mg/L)	mean	38.45	20.76	21.15	10.97	15.46	12.52
	Std. Dev.	10.67	5.61	11.27	4.05	6.60	5.98
	min	19.25	14.46	3.00	4.55	3.53	4.05
	max	62.55	30.23	44.79	20.19	24.20	23.00
	n	12	10	11	12	9	11
TP (mg/L)	mean	8.39	1.76	0.60	5.38	6.24	4.67
	Std. Dev.	5.79	0.48	0.23	1.44	1.59	1.05
	min	4.32	0.92	0.34	3.22	4.80	2.50
	max	26.00	2.40	1.20	8.70	9.90	5.90
	n	12	10	11	12	10	12

3.4.2 Total Nitrogen and Total Phosphorus Reductions

The concentrations of nitrogen and phosphorus in effluent showed significant variation among the different processes. None of the five main treatment systems met the Florida Keys nitrogen standard of 10 mg/L. The influent total nitrogen (TN) concentration during Phase II testing was significantly higher than Phase I with a mean concentration of 47.98 mg/L, representing an approximately 25% increase in TN. This in combination with increased flow resulted in a much higher loading of TN to the systems in Phase II of the study. The increase in effluent concentrations of TN, however, were insignificant in comparison to the increase in loading rate. This indicated that the systems achieved a higher removal percentage under increased nitrogen loading.

The FAS system showed the best efficiency with mean effluent TN concentration of 11.51 mg/L, followed by the RBC-ABF system with a mean value of 14.9 mg/L. These results are encouraging as they were obtained without supplemental carbon addition to enhance denitrification. The effluent concentrations for the other three systems ranged from 26.23 mg/L for RSF/ABF to 31.29 mg/L for the SDI system with LECA™ media (LLECA).

The results obtained from the “Niteless” denitrification unit (FAS-ABF) used in series after the FAS indicated that the Florida Keys standard of 10 mg/L could be achieved with the addition of supplemental carbon. Phase II results indicated a mean effluent TN concentration of 7.09 mg/L for this system.

Figure 3-3 presents the mean ± the standard deviation for the nitrogen data. The FAST unit provided the most consistent nitrogen removals over the study period. Supplemental nitrogen removal process(es) would be required for all the systems tested for effluent TN concentrations to meet Florida Keys effluent standards.

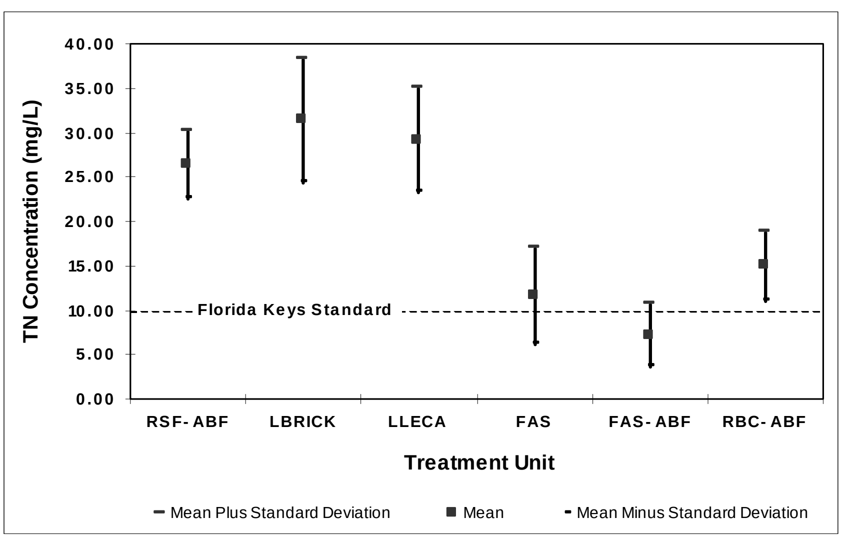

Figure 3-3. Effluent TN Concentrations (Mean ± Std. Dev.)

The total phosphorus influent concentration of 8.72 mg/L was reduced to 0.53 mg/L by the SDI system (Process Stream 2) with the LECA™ media. This was the only process stream which met the Florida Keys TP standard of 1 mg/L in Phase II testing. Significant removals were also observed in the RSF-ABF system with LECA™ media, where the TP concentration was reduced to 1.46 mg/L. All other process streams reduced the total phosphorus concentration to values ranging from 2.65 mg/L to 6.80 mg/L. The results of the Phase II testing indicate the influent values for TP were similar to Phase I testing. Effluent results indicated a significant increase in TP from the LBRICK media.

Figure 3-4 presents the mean ± the standard deviation for total phosphorus. The LECA™ media used during Phase II of the test was an improved form of LECA™, called Filterlite-P, and showed significant reduction of TP over the media used in Phase I. The Filterlite-P LECA Media SDI bed provided the most consistent TP removal during the study period.

The crushed brick media did not appear to do as well as it did during Phase I of the testing, but it is believed that a short-circuiting of the wastewater developed during replacement of the drip irrigation system in that bed. Also, the brick media cores taken during this phase probably disturbed the bed and allowed untreated wastewater to enter the saturated zone of the system.

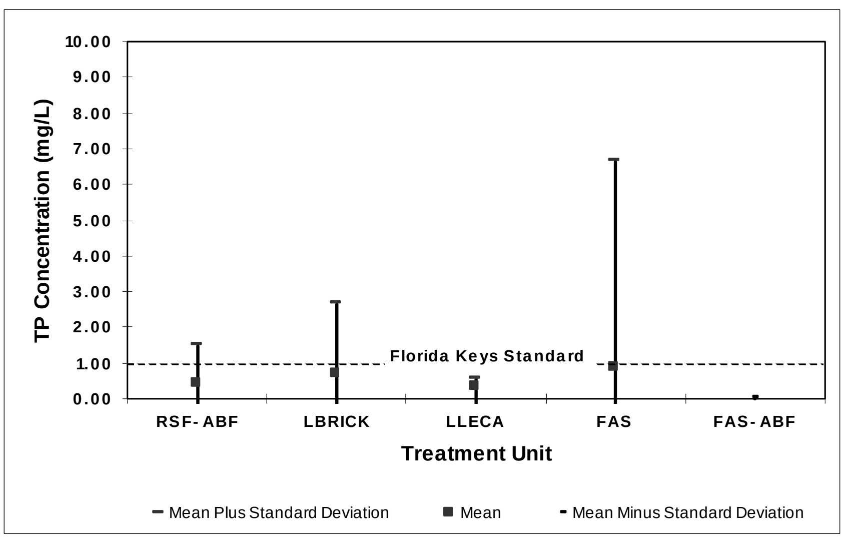

Figure 3-4. Effluent TP Concentrations (Mean ± Std. Dev.)

3.5 Drip Irrigation Bed Phosphorus Capacity

Media cores were taken from the crushed brick SDI system in April 1999. This effort was undertaken to estimate the phosphorus adsorption capacity of the SDI system and to predict the useful life of such a system for phosphorus removal to the 1 mg/L TP effluent limit. Four core samples were obtained from four different areas of the SDI bed and analyzed for TP with depth. The TP concentration at each depth was then compared to the TP concentration of a fresh crushed brick sample that had not been exposed to wastewater infiltration. The results of these analyses are provided in Table 3-5.

Table 3-5. OWNRS Phosphorus Results by Depth for Brick Chip Media

New Media Sample (mg/kg)	Depth (in.)	Sample (mg/kg)				Range	Standard Deviation	Average
		NE	NW	SE	SW			
510	0-2	830	700	900	660	660 to 900	111.77	772.50
510	4-6	740	610	730	680	610 to 740	59.44	690.00
510	8-10	620	580	600	500	500 to 620	52.60	575.00
510	10-12	580	520	550	500	500 to 580	35.00	537.50
510	12-14	530	500	520	510	500 to 530	12.91	515.00
510	14-16	460	510	610	530	460 to 610	62.38	527.50
510	16-18	500	520	530	460	460 to 530	30.96	502.50

The TP concentration of the crushed brick media samples varied considerably between the various sample locations. The surface media TP concentration (0-2" depth) ranged from, 660 to 900 mgTP/kg media, compared to 510 mg/kg for new crushed brick. This variation is probably due to differences in wastewater loading and nutrient uptake at the various sample locations.

Wastewater flowed from east to west through the drip irrigation tubing, and when problems developed with the system due to emitter clogging, the westernmost emitters clogged first and lowered loading to that end of the crushed brick bed. Therefore, it was assumed that the easternmost samples were the best representation of P-saturated media conditions. These samples contained 830 and 900 mg TP/kg media (ave=865) and indicated a field capacity of approximately 320-390 mg/kg compared to a new media sample. This capacity is approximately 1.6 to 2.0 times the capacity determined from laboratory batch isotherm tests conducted on the crushed brick media. This is typical since the field conditions often result in increased detention time under unsaturated conditions and provides opportunities for nutrient uptake by plants, which are not accounted for in the laboratory tests.

The P-adsorption media life of the SDI beds under the OWNRS test configuration can be estimated from the media core sample results. The SDI bed life for P removal would be as follows:

$$\text{P-Adsorption Bed Life} = \frac{\text{Bed Depth}}{\text{Rate of Media Utilization}}$$

where the media utilization rate is dependent on:

- Media Sorption Capacity
- Media Particle Size Distribution
- Wastewater Loading Rate
- Phosphorus Loading Rate
- Wastewater Application Method
- Unsaturated Bed Depth
- Other P-Uptake Mechanisms (i.e. plant uptake, precipitation, reactions)

At the time the crushed brick cores were collected, the weighted average loading rate to the system had been 1.35 gallons per day per ft^2 of bed area (gpd/ft^2). This was the weighted average loading rate since SDI loading began in October 1996. The media cores indicated that the saturated P-front had migrated no more than 4-6 inches into the bed, a rate of 1.7 to 2.6 inches per year under the conditions studied.

Thus, the estimated life can be calculated as follows for an unsaturated bed depth of 2 feet (24 inches):

$$\text{P-Adsorption Bed Life} = \frac{\text{24 inches unsaturated depth}}{\text{2.6 inches/yr. utilization}}$$

$$= \text{9.2 years}$$

At a 1.7 inch/year utilization rate the estimated life would increase to 24/1.7 = 14.1 years. Lower wastewater-loading rates or deeper unsaturated media depth would increase the bed life. In summary it appears that a P-adsorption Bed life of 10 years is a reasonable expectation for OWNRS in the Florida Keys based on the following conditions:

- Wastewater application rate of [1.35 gpd/ft^2.
- Subsurface Drip Irrigation of St. Augustine turf.
- Influent TP concentrations of < 9 mg/L.
- Unsaturated media bed depth 〈 2 ft.
- Fine, crushed brick media from Cherokee-Sanford Brick Company with the following specs:
    - D_{10} = 0.015 mm
    - D_{30} = 0.10 mm
    - D_{90} = 1 mm

Although the core testing was performed only on the crushed brick media, the LECA™ Filterlite-P would be expected to perform similarly based on laboratory batch tests and the performance of the LECA™ SDI bed during Phase II.

3.6 Summary of Treatment Performance

All process streams effectively reduced the $CBOD_5$ levels below a 5 mg/L average during the study period. TSS removals below 10 mg/L were observed in all systems except the RBC-ABF system, which averaged TSS effluent concentrations of 14 mg/L. The increased TSS in RBC-ABF may have been due to the carbon feed stream from the front of the RBC to the ABF.

None of the individual systems were able to achieve average total nitrogen concentrations below 10 mg/L, as required by the Florida Keys effluent standards. However, the FAST™ system was able to achieve an average of 11.51 mg/L for total nitrogen. Eighty to ninety percent of the effluent TN concentrations consisted of nitrate nitrogen (NO_3). Thus, providing additional denitrification of the system effluents could reduce effluent TN values considerably. With the addition of the “Niteless” denitrification unit the total nitrogen concentration was reduced to an average of 7.1 mg/L for a “NiteLess” ABF receiving the FAST™ effluent.

Phosphorus removal below the 1 mg/L Florida Keys Standard was observed only by the Filterlite-P LECA media SDI, although the crushed brick media should perform as well but was suspected of performance degradation due to hydraulic short-circuiting which developed during process modifications. Other adsorption media may also be available which provides similar performance in the SDI process. However, a standardized test protocol is needed to evaluate potential media consistently.

The results of Phase II when compared to Phase I, indicate equivalent performance of the majority of the treatment systems in removing CBOD5, TSS and nutrients. Because of the increase in flow, the systems under Phase II received significantly higher loading of nitrogen an phosphorus. But the systems were able to achieve effluent quality, which was compariable with the Phase I results. This indicates that the systems have achieved a higher percent removal of nutrient in Phase II of the study.

In summary, it appears that a combination of unit processes would be required to achieve onsite wastewater treatment performance that meets the current Florida Keys effluent standards. A biological treatment system which accomplishes nitrification and denitrification, and discharges effluent with TN [15 mg/L to an engineered media drip irrigation bed should meet the Florida Keys standards of 10/10/10/1 for $CBOD_5$, TSS, TN and TP, respectively, after passing through the SDI bed.

4.0 PHASE II OWNRS OPERATION AND MAINTENANCE

This section provides an evaluation of the operation and maintenance (O&M) requirements associated with the OWNRS installed at the Big Pine Key Central Testing Facility. The O&M activities are based on the experience gained from operating and maintaining the systems over the additional one year monitoring period in Phase II. The units were generally operated and maintained in accordance with the manufacturer's recommendations, or based on experience with similar systems.

4.1 OWNRS Operation and Maintenance Results

Operational activities were defined as routine actions and/or inspections used to ensure system performance in accordance with the manufacturer's recommendations. These actions typically included routine inspection of system controls and monitoring of the operating conditions of the unit. O&M activities did not change significantly during Phase II of the testing.

4.2 OWNRS Energy Consumption Results

An electricity cost of $0.10/kilowatt-hour was used to determine the daily electric cost. A summary of recorded electric use and the calculated electrical costs for the various treatment processes is presented in Table 4-1.

Table 4-1. Treatment Process Power Consumption and Cost Data, Phase II
(January 27, 1999 to December 17, 1999)

Observation Date	Process System 1 (RSF)	Process System 2 (SDI)	Process System 3 (FAS)	Process System 5 (RBC)
Number of Days in Monitoring Period	270	324	324	324
Net Electric Use (kW-hrs)	1006	309	1514	821
Average Daily Electric Use (kW-hrs/Day)	3.7	1.0	4.7	2.5
Average Daily Electric Cost ($/Day)[1]	$0.37	$0.10	$0.47	$0.25
Average Monthly Electric Cost ($/month)[2]	$11.18	$2.86	$14.02	$7.60
Average Yearly Electric Cost ($/year)	$136.00	$34.81	$170.56	$92.49

[1] Mean electrical use is based on the period of time from March 22,1999 to December 17, 1999.
[2] Average Electrical Cost Calculated on $0.10/kW-hr
[3] Monthly Cost Calculated on a 30 Day Cycle
Process System 4 Values are not included due to the system being inoperative.

Net power usage for the five process streams was monitored following system modifications for a period of 324 days. The average daily power use ranged from 1.0

kW-hr/day for the SDI (Process Stream 2) to 4.7 kW-hr/day for the FAST™ (Process Stream 3). The average electrical usage for Process System 1 was calculated based on 270 days (March 22, 1999 to December 17, 1999). An unusual spike in electrical usage was observed during the period between February 17, 1999 to March 22, 1999 for Process System 1, and data collected on power usage during this period was not considered. The cause of the electrical spike, however, could not be determined.

Process System 2 showed a decrease in power cost due to the installation of a smaller blower unit in Phase II. The blower was also connected to a timer which cycled on and off in an effort to increase nitrogen removal. These items reduced energy consumption considerably from Phase I.

4.3 OWNRS Chemical/Material Consumption Results

The “Niteless” denitrification unit located in series after the FAST™ unit was the only process tested during Phase II that required a chemical addition. This process required the addition of a carbon/bacteria media mixture to an ABF unit, and was tested on the FAST™ effluent stream.

It was observed that an application rate of 20 ounces or 0.57 kilograms (kg) of media per day resulted in an average of 7.1 milligram per liter (mg/L) or less of total nitrogen in the effluent during Phase II testing. Based on this the cost of the carbon/bacteria media is estimated to be approximately $100.00 per year.

4.4 Operation and Maintenance Cost

At the onset of the study a list of recommended operation and maintenance activities was prepared based on the experience with the treatment systems and review of the manufacturer’s installation guidelines, operation manuals, and sales information. A summary of semi-annual and annual O&M activities for the systems comparing Phase I and Phase II is presented in Table 4-2. In addition, an estimate of time to perform the activities is presented.

Table 4-2 provides only the recommended O&M activities for each system. It should be noted that the performance and operation and maintenance requirements may vary depending on the wastewater characteristics of a specific home and additional maintenance visits may be required from time to time due to equipment or parts failure.

In addition to the O&M activities listed in Table 4-2, the following activities are also anticipated for the treatment systems:

- Removal of accumulated sludge every 5 years for septic tanks and approximately every 3 years for aerobic units; and

- Effluent water quality monitoring of AWT parameters ($CBOD_5$, TSS, TN, TP) for compliance with treatment performance requirements.

Table 4-2. Comparison of OWNRS Operation and Maintenance Activities Between Phase I and Phase II.

System	Activity Performed	Semi-annual	Annual	Estimated Time to Perform Activity Per Visit, Phase I	Estimated Time to Perform Activity Per Visit, Phase II
RSF	Inspect recirculation pump operation, high water alarm system, and float operation.	X	X	10 min.	10 min.
	Inspect sand filter surface. (LECA surface, during Phase II)	X	X	10 min.	5 min.
	Observe sprayer operation. Clean spray heads. Flush out distribution lines.	--	X	10 min.	10 min.
	Record operational data (pump run time, dosing meter). Compare data to past records.	X	X	15 min.	10 min.
	Calibrate pump and recirculation ratio.	--	X	20 min.	20 min.
	Check sludge depth in septic and recirculation tanks.	--	X	10 min.	10 min.
SDI	Inspect irrigation pump operation, high water alarm system, and return flow from irrigation beds.	X	X	15 min.	15 min.
	Increase return flow and pressurize lines to flush out emitters and dripper lines.	--	X	15 min.	5 min.
	Clean effluent screen in septic tank and filter cartridges in SDI pump unit.	--	X	20 min.	10 min.
	Check pressure differential across dripper line. Adjust.	--	X	10 min.	0 min.
	Inspect bed surface for exposed dripper lines and signs of effluent surfacing. Check sludge depth in septic tank and SDI tanks.	X	X	10 min.	10 min.
	Record operational data (flow meters and pump timers). Measure return and forward flow rates. Compare data to past records.	X	X	15 min.	15 min.
FAS	Check sludge depth, primary tank.	--	X	10 min.	10 min.
	Check inspection port for aeration and blower screen. Clean filter.	X	X	20 min.	20 min.
	Check system performance with respect to blowers, controls, mixed liquor color, and system odors. Measure DO and collect mixed liquor sample and conduct settleable matter test.	X	X	30 min.	30 min.
CFCR	Check timer clock and decant pump operation.	X	X	10 min.	10 min.
	Check alarm system and float operations.	X	X	15 min.	15 min.
	Remove cover, observe air compressor aeration and mixer operation. Measure DO and collect mixed liquor sample and conduct settleable matter test.	X	X	30 min.	30 min.
	Wash off control floats and decant float.	--	X	10 min.	10 min.
	Clean air compressor filter and effluent screen from flow inducer tube.	--	X	15 min.	15 min.
RBC	Remove cover, check disk operation and biomass growth.	X	X	15 min.	15 min.
	Check sludge recirculation pump in secondary tank and recycle dipper bucket.	X	X	15 min.	15 min.
	Remove surface scum from primary tank.	--	X	10 min.	10 min.
	Check sludge depth in primary and secondary tanks.	--	X	20 min.	20 min.
	Replace Nylon bushings on rotator gear	--	X	--	20 min.
ABF	Check biomass growth and dissolved oxygen levels in the tank.	X	X	15 min.	15 min.

RSF = Recirculating Sand Filter; SDI = Subsurface Drip Irrigation; FAS = Fixed Activated Sludge; CFCR = Continuous Feed Cyclic Reactor; RBC = Rotating Biological Contactor; ABF = Anoxic Bio-Filter; ABF/Carbon = Anoxic Bio-Filter with Carbon; CPU = Chemical Precipitation Unit.

5.0 SUMMARY AND CONCLUSIONS

A field evaluation of several onsite wastewater nutrient reduction systems (OWNRS) was continued for a second phase to evaluate longer-term treatment effectiveness by OWNRS in the Florida Keys. Results indicated that the systems evaluated provided excellent treatment but no individual system was capable of meeting all effluent standards currently in place for the Florida Keys (10 mg/L $CBOD_5$, 10 mg/L TSS, 10 mg/L TN, and 1 mg/L TP). However, all systems were able to meet the $CBOD_5$ and TSS requirements. Based on the evaluation conducted at the Big Pine Key testing facility to date, the following conclusions are presented:

1) Florida Keys effluent standards for $CBOD_5$, TSS, and TP can be met consistently with the engineered media SDI system or combining other systems/processes evaluated;

2) TN reductions of > 70 % are achievable by biological nitrification/denitrification and could be increased with process optimization and/or supplemental carbon addition; the FAST™ combined with a NiteLess™ ABF unit averaged 7.1 mg/L TN during the Phase II Study.

3) A combination of various unit processes evaluated would achieve treatment performance by onsite wastewater systems, which meets current effluent standards. A biological treatment system which incorporates nitrification/denitrification (>70% TN reduction) and discharges to an engineered media SDI bed should consistently meet the current Florida Keys standards for $CBOD_5$, TSS, TN and TP. With process optimization and/or supplemental carbon addition, such a system should produce effluent close to the AWT nitrogen standard, as discharged from the SDI bed.

4) Construction and operation costs of OWNRS will be considerably greater than conventional OWTS. Estimated total annual costs for the OWNRS evaluated, were described in detail in the Phase I OWNRS Report (Ayres Associates, 1998) and ranged from $1,730 to $2,841 per year.

5) The phosphorus adsorption SDI beds were estimated to have a useful life of approximately 10 years based on study conditions during the OWNRS project. This conclusion was based on estimates from core samples of the crushed brick media SDI bed and analyses of P migration with depth.

6) Continued monitoring of the OWNRS should be conducted to further quantify phosphorus removal capacities and treatment performance longevity, solids handling requirements, and long term maintenance requirements of OWNRS at the facility.

6.0 REFERENCES

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