Florida Keys Onsite Wastewater Nutrient Reduction Systems Demonstration Project

FLORIDA DEPARTMENT OF HEALTH

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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. Excess nutrient loading is a suspected cause. The Sanctuary consists of approximately 3,668 square miles of coastal and oceanic waters and the submerged land beneath them. The shoreward boundary of the sanctuary is the mean high-water mark. Figure 1-1 outlines the location and boundary of the Florida Keys National Marine Sanctuary (FKNMS).

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

The water quality protection program identified nutrient loading from domestic wastewater sources as one of the major water quality concerns in the Keys (US EPA, 1993). Fourteen recommendations for projects and programs to address domestic wastewater problems were presented (Table 1-1) in the final Water Quality Protection Program document (US EPA, 1996). Several of the recommendations involved projects and programs for onsite wastewater treatment systems (OWTS), and led to the development of the project described in this report.

Reference: DeLorme Mapping

Figure 1-1. Florida Keys National Marine Sanctuary Boundary

Table 1-1. Water Quality Protection Program Recommendations Addressing Domestic Wastewater (US EPA, 1996).

Inspection/Compliance Program - Establish authority for and implement inspection/enforcement programs including elimination of unregulated cesspits.	**High Priority**
OWTS Demonstration Project - Conduct a demonstration project to evaluate alternate, nutrient-removing OWTS.	**High Priority**
Advanced Wastewater Treatment (AWT) Demonstration Project - Conduct a demonstration project to evaluate installation of a small, expandable AWT plant to serve an area of heavy OWTS use with associated water quality programs.	**High Priority**
Nutrient Reduction Targets - Conduct research to develop nutrient reduction targets necessary to restore and maintain water quality and Sanctuary resources.	**High Priority**
Sanitary Wastewater Master Plan - Develop a Sanitary Wastewater Master Plan for the Florida Keys. Based on results of the demonstration projects and preliminary nutrient reduction targets, the Master Plan would evaluate options for further wastewater treatment (i.e., beyond eliminating cesspits and enforcing existing standards), and specify details of costs, schedules, service areas, etc. for implementation.	**High Priority**
Master Plan Implementation - Implement the preferred wastewater treatment option selected in the Sanitary Wastewater Master Plan.	**High Priority**
City of Key West Ocean Outfall - Upgrade effluent disposal of City of Key West wastewater treatment plant. Evaluate deep well injection, including the possibility of effluent migrating through the boulder zone into Sanctuary waters. Evaluate options for reuse of effluent, including irrigation and potable reuse. Discontinue use of the existing ocean outfall and implement deep well injection, aquifer storage, and/or reuse.	**High Priority**
Water Quality Standards - Develop and implement water quality standards, including biocriteria, appropriate to Sanctuary resources.	**Med. Priority**
NPDES Program Delegation - Delegate administration of the NPDES program for Florida Keys dischargers to the state of Florida.	**Low Priority**
Resource Monitoring of Surface Discharges - Require all NPDES-permitted surface dischargers to develop resource monitoring programs.	**Low Priority**
Improved Interagency Coordination - Improve interagency coordination for industrial wastewater discharge permitting.	**Low Priority**
Combined OWTS Permitting Responsibilities - Combine OWTS permitting responsibilities under one agency for commercial establishments, institutions, and multi-family residential establishments that rely on injection wells.	**Low Priority**
Monitoring of Revised OWTS Responsibilities - Monitor revised rules designed to improve the performance of OWTS in the Florida Keys.	**Low Priority**
Laboratory Facilities - Establish an interagency laboratory capable of processing monitoring and compliance samples.	**Low Priority**

1.2 Summary of Domestic Wastewater Nutrient Loading

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.

The domestic wastewater facilities in the Keys include about 24,000 regulated OWTS; 8,000 unregulated cesspits; over 250 small package treatment plants; and 2 municipal wastewater treatment plants (US EPA, 1996). The estimated nutrient loadings from these sources are summarized in Table 1-2.

Table 1-2. Estimated Domestic Wastewater Nutrient Loading in the Florida Keys (US EPA, 1996).

Source	Total Nitrogen		Total Phosphorus	
	lbs./day	Percent of Total	lbs./day	Percent of Total
OWTS	932	39.2	226	41.6
Cesspits	283	11.9	100	18.4
Package plants (groundwater discharge)	758	31.9	152	27.9
Municipal wastewater treatment plants (surface discharge, NPDES)	320	13.5	36	6.6
Live-aboards	84	3.5	30	5.5
Total	2377	100	544	100

These loadings assume that all wastewater nutrients, including groundwater discharges, eventually reach surface waters. OWTS and cesspits reportedly account for approximately 50% of the estimated wastewater nitrogen and 60% of the estimated wastewater phosphorus loading respectively (US EPA, 1996). The extensive use of OWTS and cesspits, combined with severely limited soils and past OWTS practices, has resulted in substantial nutrient loadings to groundwater and surface water in the Sanctuary (US EPA, 1996). Degraded water quality has been documented in confined waters such as canal systems where there are large numbers of OWTS and/or cesspits (US EPA, 1992). Additional studies document linkages between OWTS enrichment of nearshore waters and the effects on water quality and biota (Lapointe, 1995).

1.3 Purpose of Project

The water quality protection program identified nutrient loading from wastewater sources as one of the major water quality concerns in the Keys. OWTS were targeted as one of the primary wastewater sources of the nutrients 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 purpose of the project was to evaluate the nutrient removal efficiency, reliability, consistency, operation and maintenance requirements, and costs associated with OWNRS.

1.4 Project Objectives

The Florida Keys OWNRS Demonstration Project was designed to demonstrate the use and capability of alternative OWTS technologies for the Florida Keys. 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 additional goal of the project was to determine if the Florida advanced wastewater treatment (AWT) standards of 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), are feasible for OWTS. These AWT standards are referred to as 5/5/3/1 effluent quality standards.

1.5 Project Scope

The OWNRS demonstration project consisted of detailed treatment system performance evaluations at a central test facility (CTF) on Big Pine Key and general field evaluations of alternative onsite systems installed at three individual homes in the Lower Keys.

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. Both "passive" and "active" systems were tested. The CTF allowed accurate monitoring of influent wastewater flows and the capability for flow-composited effluent sampling to determine treatment performance. In addition to treatment performance, the operation, maintenance, and costs associated with each system were monitored over a one year test period.

In addition to the CTF testing, subsurface drip irrigation (SDI) systems were installed at three individual homes in the Lower Keys. These systems are relatively passive in operation, and were monitored for operation, maintenance, and user acceptance. The treatment performance of various SDI systems was evaluated at the CTF where they could be directly compared to other treatment technologies.

1.6 Report Organization

This report is organized into nine main sections. Section 1, as presented herein, provides a brief background about the Florida Keys National Marine Sanctuary, the Water Quality Protection Program, potential problems with OWTS in the Florida Keys, and the need for the Onsite Wastewater Nutrient Reduction System demonstration project.

Section 2 - Florida Keys Environment, describes the Keys' geology/hydrogeology, climatology, and demographics and their impacts on OWTS.

Section 3 - Residential Wastewater Characteristics and Treatment, provides a brief review of literature on expected nutrient quantities in residential wastewater, typical nutrient removal processes in wastewater, and also nutrient removal processes by OWTS.

Section 4 - CTF Design and Study Methodology, presents the study plan for the OWNRS project, and outlines the site selection, OWNRS process selection, and the materials and methods used to collect the testing data.

Section 5 - Treatment Performance Results, presents the results of the OWNRS testing program including the laboratory analytical data and provides a statistical evaluation of the data.

Section 6 - System Operation and Maintenance, provides a summary of the OWNRS operation and maintenance (O&M) activities and the associated costs.

Section 7 - Cost Evaluation, presents the capital costs to install the OWNRS and the life cycle costs associated with the operation of the systems tested.

Section 8 - Individual Home System Demonstration, discusses the demonstration and monitoring of subsurface drip irrigation systems installed at three homes in the Keys.

Section 9 - Conclusions and Recommendations, provides discussion and a list of conclusions from the project and recommendations for wastewater treatment options for individual homes in the Keys. This section also identifies the limitations of the project and provides recommendations for future work.

2.0 FLORIDA KEYS ENVIRONMENT

Conventional onsite wastewater treatment systems (OWTS) are directly impacted by the type of environment in which they operate. Environmental conditions such as area geology/hydrogeology, seasonal water table, and climate all have direct impacts on OWTS performance. Additional area conditions such as local demographics and land uses also effect the design and performance of OWTS. This section briefly discusses the environment of the Florida Keys, as related to OWTS.

2.1 Florida Keys Physical Environment

The geology, hydrogeology, and climatology of the Florida Keys create unique conditions in which OWTS must operate. These conditions must be considered in developing appropriate OWTS designs that will meet established water quality goals.

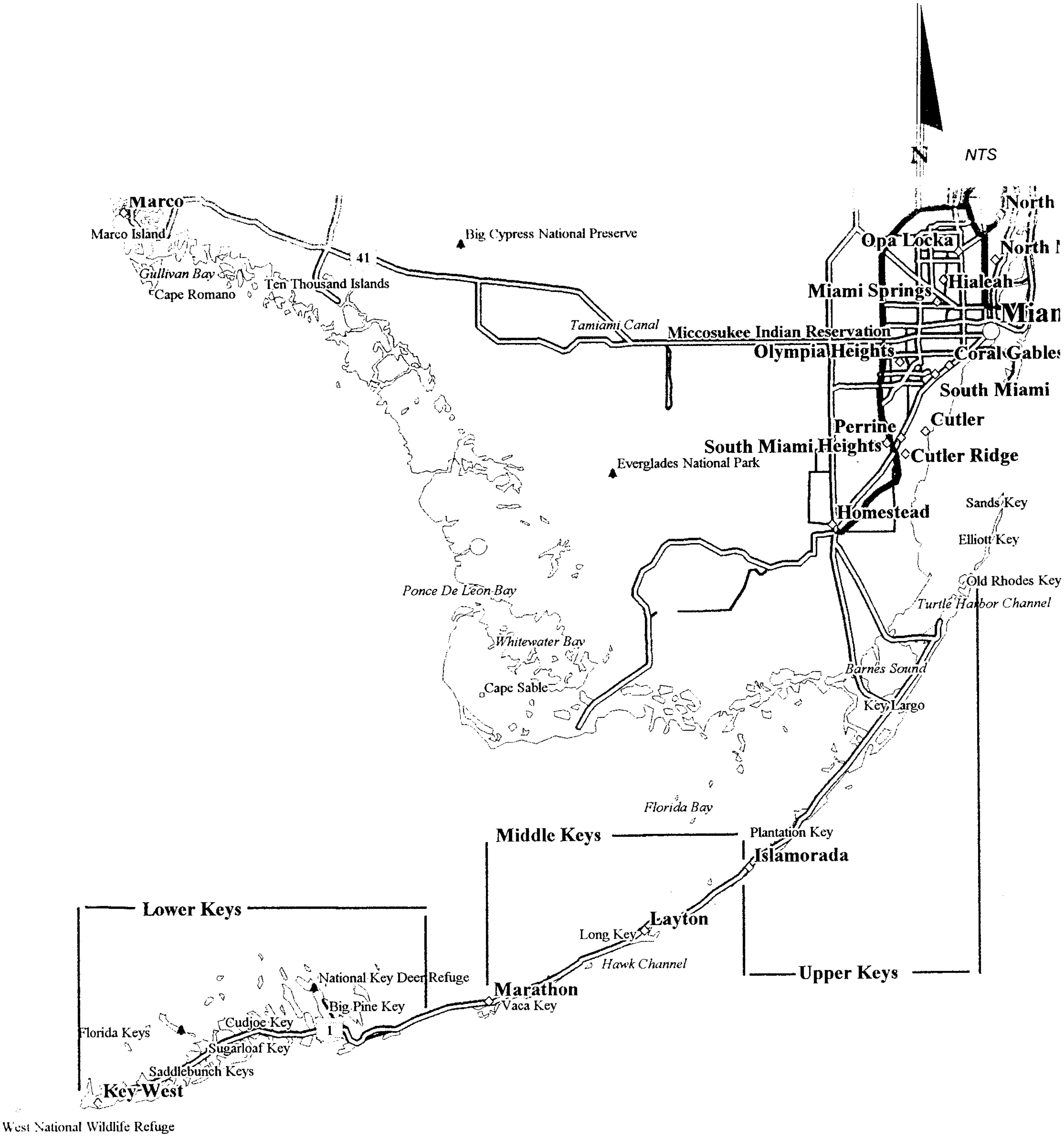
2.1.1 Geology/Hydrogeology

The Florida Keys are a limestone island archipelago extending southwest over 200 miles from the southern tip of the Florida mainland to the Dry Tortugas. The Keys are made up of over 1,700 islands encompassing about 103 square miles. They are divided into three regions: 1) the Upper Keys, from the mainland to Upper Matecumbe Key; 2) the Middle Keys, from Upper Matecumbe Key to the Seven Mile Bridge; and 3) the Lower Keys from Little Duck Key to Key West (Figure 2-1).

The Florida Keys are low-lying, with an average elevation of 3 to 6 feet above sea level. The Middle Keys are generally smaller than the Upper and Lower Keys with numerous wide channels separating each island.

The surface of the Upper and Middle Keys is composed of Key Largo Limestone. The Key Largo Limestone is a coralline limestone composed of coral heads encased in a matrix of calcarenite. The thickness of the formation ranges from 75 to 170 feet and exhibits high porosity and permeability. It occurs below the surface as far north as Miami Beach to as far south as Bahai Honda. Near the northern and southern limits of the Key Largo Limestone, it is overlain conformably by the Miami Limestone (Florida Geological Survey, 1992).

The Lower Keys (with the exception of Little Duck Key, the Newfound Harbor Keys, and a portion of Big Pine Key) are composed of oolitic Miami Limestone. The Miami Limestone is made up of two facies, the oolitic and bryozoan. The bryozoan facies underlies and extends west of the western boundary of the oolitic facies. The bryozoan facies consists of calcareous bryozoan colonies imbedded in a matrix of ooids,



Reference: DeLorme Mapping

Figure 2-1. Lower, Middle, and Upper Section of Florida Keys

pellets, and skeletal sands. The oolitic facies consists of variably sandy limestone composed primarily of oolites with scattered concentrations of fossils. The oolite formation is thin over the southern border of the Lower Keys, reaching a maximum thickness of 40 feet on the northern part of Stock Island. The channels between the Lower Keys are the remnants of the original tidal channels that developed in the sand shoals. The Miami Limestone exhibits high porosity but lower permeability than Key Largo Limestone (NOAA, 1996).

Because of the low topographic relief and pervious nature of the Key Largo and Miami Limestone formations, most rainfall in the Keys infiltrates the surface and forms shallow freshwater lenses. Groundwater in the Keys is restricted to these shallow lenses and deeper waters of the Floridan Aquifer. The freshwater lense generally becomes thicker during the rainy season and thinner or absent during the dry season (NOAA, 1996). Only the largest Keys, such as Big Pine Key, maintain a permanent fresh water lense suitable for water supply wells.

The Floridan aquifer underlies the Miami Limestone. The sediment that comprises the Floridian aquifer system underlies all of Florida, although potable water is not present everywhere. The aquifer's surface in South Florida is generally 500 to 1000 feet deep and its average thickness is about 3000 feet. It is divided into three hydrogeological units; 1) the upper Floridan; 2) the middle confining unit; and 3) the lower Floridan aquifer. In south Florida and the Keys, the upper Floridan aquifer contains brackish groundwater, while the lower Floridan aquifer contains salt water.

Soils in the Keys are very thin over shallow bedrock. The physical characteristics of all soil types present in Monroe County are rated by USDA to have severe or very severe limitations for conventional OWTS. Generally, there is insufficient soil depth to provide purification of septic tank effluent before it reaches the groundwater. Due to the porous nature of the rock combined with tidal influences, the use of conventional OWTS in the Keys may result in inadequately treated sewage leaching into the waterways of the Keys (Monroe County, 1992).

2.1.2 Florida Keys Climatology

The Keys have a tropical maritime climate. There are essentially two seasons: 1) Summer which last from May to October; and 2) Winter which lasts from November to April. The summer season is characterized as wet with numerous thunderstorms. The winter months are typically dry with infrequent, fast moving cold fronts. The climate is influenced primarily by the warm waters of the Gulf and Atlantic, the Florida Current, and the Gulf Stream.

The Keys have very moderate temperatures with an annual average high temperature of 82.4°F and an average annual low temperature of 75.4°F. The prevailing easterly winds which pass over the Gulf Stream transport warm air over the Keys. Cold fronts which approach from the north are warmed by the Gulf and Florida Bay waters. The Keys have very little land mass in which to modify the air temperature. The air temperature reflects the surface conditions of the water which maintains the warmer temperatures. Average temperature variation is about 2°F from the Upper to the Lower Keys. The highest daily average temperature of 89.6°F occurs in July and August and the lowest daily average temperature of 66.2°F typically occurs in February. Temperature below freezing has never been recorded in the Keys.

The Keys are one of the driest areas in Florida with an average of 49 inches of precipitation per year. The highest monthly mean rainfall occurs in September (6.5 inches) and the lowest monthly mean rainfall of 1.3 inches occurs in March (NOAA, 1996). The lack of precipitation can be attributed to minimal well-established land/sea breezes and the limited number of large-scale synoptic systems in the area. The majority of the rainfall occurs during summer in the form of locally intense convective storms. A small percentage (18 to 33 percent) of the area's precipitation occurs during the winter. Precipitation peaks in June and the latter part of September. Drought conditions are not common; however, they can occur at any time when stable, stationary air masses inhibit convection.

2.1.3 Demographics

The population of Monroe County grew from 14,078 to 78,024 during the past 50 years, resulting in an increase of approximately 64,000 people (Monroe County, 1992). The most dramatic increases in population in recent years have occurred in Key Largo, Marathon, and Big Pine Key. During a peak period in 1990, seasonal visitors were estimated at 56,600 which includes those living in residential accommodations, tourist facilities, live-aboard vessels, or with local residents. The sum of the peak seasonal and resident population has been estimated at about 134,600 with a population density of 1,300 persons per square mile (Monroe County, 1992).

Peak tourist populations occur during the first quarter (January to March) of each year. The tourist season is slightly longer in the Upper Keys than in the Lower Keys mainly due to weekend tourists from Miami and South Florida.

Future population growth is expected to be dramatically curtailed, based on the Monroe County Year 2010 Comprehensive Plan as implemented through the Monroe County Rate of Growth Ordinance (ROGO). Under this ordinance, development is limited to 255 equivalent residential units per year (including hotel, motel, and condominium units) (Monroe County, 1992). Most of the growth is expected to occur as single family homes, built in areas currently platted.

2.2 Influence of Keys Environment on Wastewater Treatment

The environment of the Florida Keys presents unique challenges for wastewater treatment, especially for onsite wastewater treatment systems (OWTS). The challenges includes the Keys' geology, demographics, and hydrogeology. The surficial geology consists of Key Largo Limestone or Miami Oolite which provides little or no overlying soil on the carbonate rock formations. The lack of a sufficient soil system poses significant problems for the use of conventional OWTS which rely on the soil to provide wastewater treatment. The rock formations also make sanitary sewer system construction difficult and expensive.

Most of the islands have limited land area, therefore residential development and associated OWTS are located along canals or within a short distance of nearshore waters. The limited land area makes future upgrades of OWTS servicing older residential communities a problem because many of these areas are clusters of small lots.

The Keys seasonal population, which almost doubles during the winter months also presents a problem for the design of wastewater treatment systems. The volume of wastewater that must be treated and disposed increases substantially. The results of the increase in general population and seasonal visitors is increased nutrient loading to nearshore waters.

Many of the OWTS and small wastewater treatment plants discharge treated wastewater to the groundwater via boreholes. Groundwater in the Keys is mostly brackish or saline, and in many locations rises and falls with the tide due to proximity to the sea and porous nature of the limestone formations. Thus, wastewater contaminants which are discharged to the shallow groundwater system have a relatively short time of travel to the nearshore waters.

3.0 RESIDENTIAL WASTEWATER CHARACTERISTICS AND TREATMENT PROCESSES

3.1 Pollutant Quantities in Residential Wastewater

Wastewater discharged from single family homes is comprised of a number of components generated from various water using activities. These activities typically include toilet flushing, bathing, clothes and dish washing, cleaning activities, and in some instances garbage disposal and water conditioning brines. The characteristics of the wastewater are influenced by many factors such as family size, age group, socioeconomic status, and family mobility and occupation, and large variations in wastewater quality may exist between homes.

Ranges of typical residential wastewater pollutant mass loadings and observed concentrations are presented in Table 3-1. Both the typical per capita mass loadings of pollutants and the concentration of the pollutants in raw wastewater are presented. The wastewater is typical of residential dwellings equipped with standard water-using fixtures and appliances that collectively generate approximately 45 gallons per capita per day (U.S. EPA, 1992). It should be noted that raw wastewater from individual homes often contains higher concentrations of these pollutants than municipal domestic wastewater because infiltration/inflow is typically not present in individual home wastewater.

Table 3-1. Pollutant Quantities in Residential Wastewater (1).

Constituent	Mass Loading (gm/cap/day)	Concentration (mg/L)(2)
5 day Biochemical Oxygen Demand (BOD_5)	35 - 65	200 - 400
Total Suspended Solids (TSS)	35 - 70	200 - 400
Total Nitrogen (TN)	6 - 17	35 - 100
Total Phosphorus(3) (TP)	2 - 3	12 – 18

(1) For typical residential dwellings equipped with standard water-using fixtures and appliances based on results presented in Bauer et al. (1979), Bennett and Linstedt (1975), Laak (1975), Laak (1986), Siegrist et al. (1976), Metcalf & Eddy (1991), and Sedlak (1991).
(2) Assumed water use of 45 gpcd (170 lpcd).
(3) The increased use of non-phosphate detergents in recent years has lowered the TP concentrations from the early literature values. Therefore, Sedlak (1991) was used for TP data.

Water use data from the Florida Keys Aqueduct Authority (FKAA) indicates that the average residential interior water use in the Keys is approximately 160 gallons/house/day. The cost of water in the Keys is relatively high, and there is little exterior water use at most residences. A daily wastewater flow of approximately 160 gallons/house/day is therefore used for average Keys wastewater flows. Thus, it is assumed that residential wastewater characteristics in the Keys are similar to the values presented in this section, with the possible exception of phosphorus, which is discussed below.

Specific water-using activities within the home contribute different quantities of pollutants to the total wastewater flow. The individual activities may be grouped into three major wastewater fractions. They are: 1) gray water (sink, shower/bath, dishwasher, clothes washer), 2) black water (toilet wastes), and 3) garbage disposal. A summary of the average contribution of several key pollutants by these activities is presented in Table 3-2 (U.S. EPA, 1992).

Table 3-2. Residential Wastewater Pollutant Contributions by Source (gm/cap/day)[1,2] and (% of total).

Parameter		Garbage Disposal	Toilet	Bathing, Sinks, Appliances	Approximate Total
BOD_5	mean	18.0 (28%)	16.7 (26%)	28.5 (45%)	63.2 (100%)
	range	10.9 - 30.9	6.9 - 23.6	24.5 - 38.8	
TSS	mean	26.5 (37%)	27.0 (38%)	17.2 (24%)	70.7 (100%)
	range	15.8 - 43.6	12.5 - 36.5	10.8 - 22.6	
Nitrogen	mean	0.6 (5%)	8.7 (78%)	1.9 (17%)	11.2 (100%)
	range	0.2 - 0.9	4.1 - 16.8	1.1 - 2.0	
Phosphorus[3]	mean	0.1 (4%)	1.6 (59%)	1.0 (37%)	2.7 (100%)

(1) Adapted from U.S. EPA (1992).
(2) Means and ranges for BOD, TSS, and TN are results reported in Bennett and Linstedt (1975), Laak (1975), Ligman et al. (1974), Olsson et al. (1968), and Siegrist et al. (1976).
(3) The increased use of non-phosphate detergents in recent years has lowered the TP concentrations from early literature values. Therefore, Sedlak (1991) was used for TP data.

In recent years, the manufacture of phosphate-free laundry detergents has increased significantly. Currently, all major national laundry detergent brands in the U.S. are non-phosphate (DeCarvalho, 1997). Since laundry detergents were a major contributor of phosphorus to the waste stream, the use of phosphate-free detergents has caused phosphorus concentrations in residential wastewater to drop considerably since the wastewater characterization studies by Bennett and Linstedt (1975), Laak (1975), Ligman et al. (1974), Olsson et al. (1968), and Siegrist et al. (1976). The phosphorus data reported by Sedlak (1991) was therefore used in Tables 3-1 and 3-2.

Many onsite wastewater treatment systems (OWTS) include a septic tank. The septic tank provides partial treatment of raw wastewater. The primary removal mechanism is sedimentation and flotation of suspended solids. Anaerobic digestion of the retained solids occurs within the tank, converting some of the solids into soluble forms which allows them to escape with tank effluent. The quality of septic tank effluent can vary substantially, but various studies have shown domestic septic tank effluent to vary within typical ranges (Table 3-3). The phosphorus data reported in Sherman and Anderson (1991) are probably the most representative of current wastewater phosphorus concentrations from septic tank effluents.

Table 3-3. Concentrations of Key Pollutants in Septic Tank Effluent [(1)], Various Studies.

Parameter (units)	SSWMP (1978)	Harkin et al. (1979)	Ronayne et al. (1982)	Sherman and Anderson (1991)
Location	Wisconsin	Wisconsin	Oregon	Florida
No. Septic Tanks Sampled	7	33	8	8
BOD_5 (mg/L)	138 7 - 480 150	132 - 145	217 - 70	141 111 - 181 36
TSS (mg/L)	49 10 - 695 148	87 - 164	146 - 70	161 64 - 594 36
Total Nitrogen (mg/L)	45 9 - 125 99	82 - 127	57.5 - 57	39.1 33 - 54 36
Total Phosphorus (mg/L)	13 0.7 - 90 99	21.8 - 215	- - -	11 7 - 15 36

(1) Data for each parameter corresponds to the average, range, and number of samples, respectively. For example, the average value of BOD_5 determined in Wisconsin was 138 mg/L. The observed range was between 7 and 480 mg/L for 150 samples.

3.2 Processes for Onsite Wastewater Treatment

3.2.1 Levels of Treatment

When discussing wastewater treatment processes, three levels of treatment are typically defined. These are primary, secondary, and advanced wastewater treatment.

Primary Treatment: Primary treatment removes gross solids from the waste stream and the majority of settleable solids, greases, oils and other floatable solids. Primary treatment provides a partially clarified effluent, but does not remove all suspended solids, dissolved organic materials, or other soluble pollutants from the wastewater stream.

Secondary Treatment: Secondary treatment provides removal of dissolved organic materials and further removal of suspended solids. Secondary treatment processes are generally considered to remove greater than 85% of the BOD and suspended solids from the wastewater stream, but only provide limited removal of the nutrients nitrogen and phosphorus.

Advanced Secondary Treatment: Advanced secondary treatment (AST) may be required to meet more stringent levels of treatment because of the disposal option and/or the location of the treatment facility. As of March 1998, treatment facilities under jurisdiction of the Florida Department of Health (DOH) in the Florida Keys are required to provide AST to reduce nutrient loading to ground water and surface waters. According to Rule 64E-6.025(1), FAC, interim operational criteria for AST requires annual arithmetic mean limits in the Florida Keys not to exceed the following:

- Carbonaceous 5-day Biochemical Oxygen Demand ($CBOD_5$) 10 mg/L
- Total Suspended Solids (TSS) 10 mg/L
- Total Nitrogen (TN) 10 mg/L
- Total Phosphorus (TP) 5 mg/L

Advanced Wastewater Treatment: Advanced wastewater treatment (AWT) provides further removal of nutrients, BOD, and suspended solids. Generally, AWT processes can provide removals of greater than 95% for BOD and suspended solids and greater than 90% for nitrogen and phosphorus. In Florida, AWT standards require monthly average effluent concentrations below the following limits:

- $CBOD_5$ 5 mg/L
- TSS 5 mg/L
- TN 3 mg/L
- TP 1 mg/L

3.2.2 Wastewater Treatment Processes

The fundamental processes used in all wastewater treatment systems to achieve these levels of treatment are defined as physical, chemical, and/or biological unit processes. Most treatment systems, including OWTS, include combinations of these treatment process types.

Physical Treatment Processes: The most typical physical treatment processes include sedimentation, screening, and filtration. Sedimentation is the gravitational settling of solids in the wastewater stream which are heavier than water, and takes place in a sedimentation tank or clarifier. Such systems can also remove solids which are lighter than water through flotation. Screening is used to remove particles from wastewater which are larger than the internal diameter of the screen openings. Filtration uses a porous media such as sand or fabric to remove suspended materials by straining, and the particle size removed depends on the pore size of the filtration medium.

Chemical Treatment Processes: Chemical treatment processes utilize a chemical reaction to alter the state of wastewater constituents so they are more easily removed from the wastewater stream. For example, to remove phosphorus, chemicals such as alum or ferric chloride can be added to the wastewater which react with dissolved phosphate to create a solid compound which can then be physically removed by sedimentation as a chemical sludge. Most chemical treatment processes are combined with a physical process for ultimate removal, and the term physical/chemical treatment processes has evolved to describe these treatment methods. Other example of physical/chemical treatment processes include ion exchange, adsorption, and reverse osmosis.

Biological Treatment Processes: The biological processes utilize microbes to alter the state of wastewater constituents. Microbes utilize organic materials and nutrients in wastewater as a food source, and break down these materials to harmless end products or incorporate them into cell tissue. Biodegradable organic materials in wastewater are measured using a term called biochemical oxygen demand, or BOD. The BOD of a wastewater is simply the amount of oxygen utilized by microbes while breaking down the organic materials in the waste, and is a simple measure of the organic strength of the wastewater.

Biological treatment processes which remove wastewater BOD and nutrients are classified as ***suspended-growth*** or ***attached-growth***. ***Suspended-growth*** processes maintain a culture of organisms in suspension in the wastewater liquid, either by aeration or mechanical mixing. The most common of these processes is known as the activated sludge process, and many variations of this process exist. Many of the aerobic treatment units (ATUs) typically used in the Keys utilize suspended growth biological processes. In ***attached-growth*** biological processes, the organisms responsible for treatment are attached to the surfaces of media such as rocks, sand, plastic or other specially designed materials. The wastewater then flows over the media surface and the attached organisms consume the organic materials in the wastewater as it passes. Intermittent sand filters (ISF), rotating biological contactors (RBC), and trickling filters are examples of attached growth biological processes.

Biological treatment processes are also generally classified as either ***aerobic*** or ***anaerobic***. ***Aerobic*** biological processes consist of organisms which use oxygen for respiration and thus require a source of air to the process. ***Anaerobic*** biological processes use organisms which do not require oxygen and aeration is not required. Aerobic processes are more rapid than anaerobic processes, and thus require less time and tank volume for the treatment process to occur. Aerobic and anaerobic biological processes can be either suspended-growth or attached-growth systems.

Biological treatment processes are the most common means of nitrogen removal from wastewater. Under aerobic conditions and long residence times, nitrifying microorganisms convert much of the organic and ammonia nitrogen in wastewater to nitrate nitrogen. If nitrified effluent is then placed under anoxic conditions, denitrifying microorganisms utilize nitrate as an energy source and convert the nitrate to gaseous forms of nitrogen, which are discharged to the air. This reaction requires a bio-available source of carbon for denitrifying organism synthesis and a lack of free oxygen in the system. Also, the denitrification reaction requires temperatures above 5°C and the reaction rate increases with increasing temperature. The high temperatures in south Florida make nitrification/denitrification a relatively efficient process for nitrogen removal.

Wastewater Treatment by Natural Systems: Natural systems are treatment systems which use soils or the natural landscape as a treatment medium. These systems typically include wastewater treatment processes involving complex interrelationships between soil, plant, and microbial communities. Natural systems include combinations of numerous physical, chemical and biological processes which occur in nature to provide renovation of the applied wastewater. Examples of natural systems which are used for onsite wastewater treatment include subsurface wastewater infiltration systems (SWIS), landscape irrigation systems, and various wetlands systems. Natural systems are relatively passive in their operation and maintenance and are ideally suited for onsite wastewater treatment at individual residences, where homeowners are typically responsible for system operation and maintenance.

4.0 CENTRAL TEST FACILITY DESIGN AND STUDY METHODOLOGY

4.1 Plan of Study

The Florida Keys Onsite Wastewater Nutrient Reduction Systems (OWNRS) Demonstration Project was designed to demonstrate the capability and use of alternative onsite wastewater treatment system (OWTS) technologies for the Florida Keys. 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 additional goal of the project was to determine if the Florida advanced wastewater treatment (AWT) standards of 5 milligrams per liter (mg/L) carbonaceous biological oxygen demand (CBOD) and total suspended solids (TSS), 3 mg/L for total nitrogen (TN), and 1 mg/L for total phosphorus (TP), are feasible for OWTS. In order to accomplish these goals the project was divided into two parts: 1) Construction of a central test facility (CTF) and side by side demonstration and monitoring of alternative treatment systems, and 2) Installation and monitoring of relatively passive treatment systems at three individual home sites. This section describes the design and study methodology at the central test facility. The individual home treatment systems are described in Section 8.0.

The demonstration and performance evaluation of various unit processes for onsite wastewater treatment was accomplished at the CTF, which was constructed at a minimum security correctional institution on Big Pine Key, Florida. The CTF was designed to allow comparative testing of numerous onsite wastewater treatment processes simultaneously, under controlled conditions, with a common wastewater source. Use of a common source eliminated the difficulty of making valid comparisons of technology performance based on a limited number of installations with widely varying wastewater characteristics. The test facility allows accurate monitoring of influent wastewater quality and flow, and the capability for flow-composited effluent sampling to determine treatment performance.

4.2 Big Pine Key Central Test Facility

4.2.1 Demonstration Site Selection

Numerous facilities in the Keys were initially identified as potential sites for a demonstration and testing facility. Site visits were made to all the locations and wastewater samples were collected from the most promising facilities. Criteria used to evaluate the potential sites included:

- Domestic wastewater quality;
- Sufficient daily wastewater volume;
- Area available for a demonstration facility;
- Availability of water and electricity;
- Suitable facilities for effluent disposal.

The Big Pine Key Road Prison (BPKRP) located on Big Pine Key was selected as the most feasible site to construct the demonstration facility (Figure 4-1). BPKRP is a minimum security correctional institute which houses non-violent inmates. The facility includes several inmate dormitories, a kitchen, and a laundry facility. BPKRP is served by an 8000 gallon per day (gpd) domestic wastewater treatment plant (WWTP) located on the property.

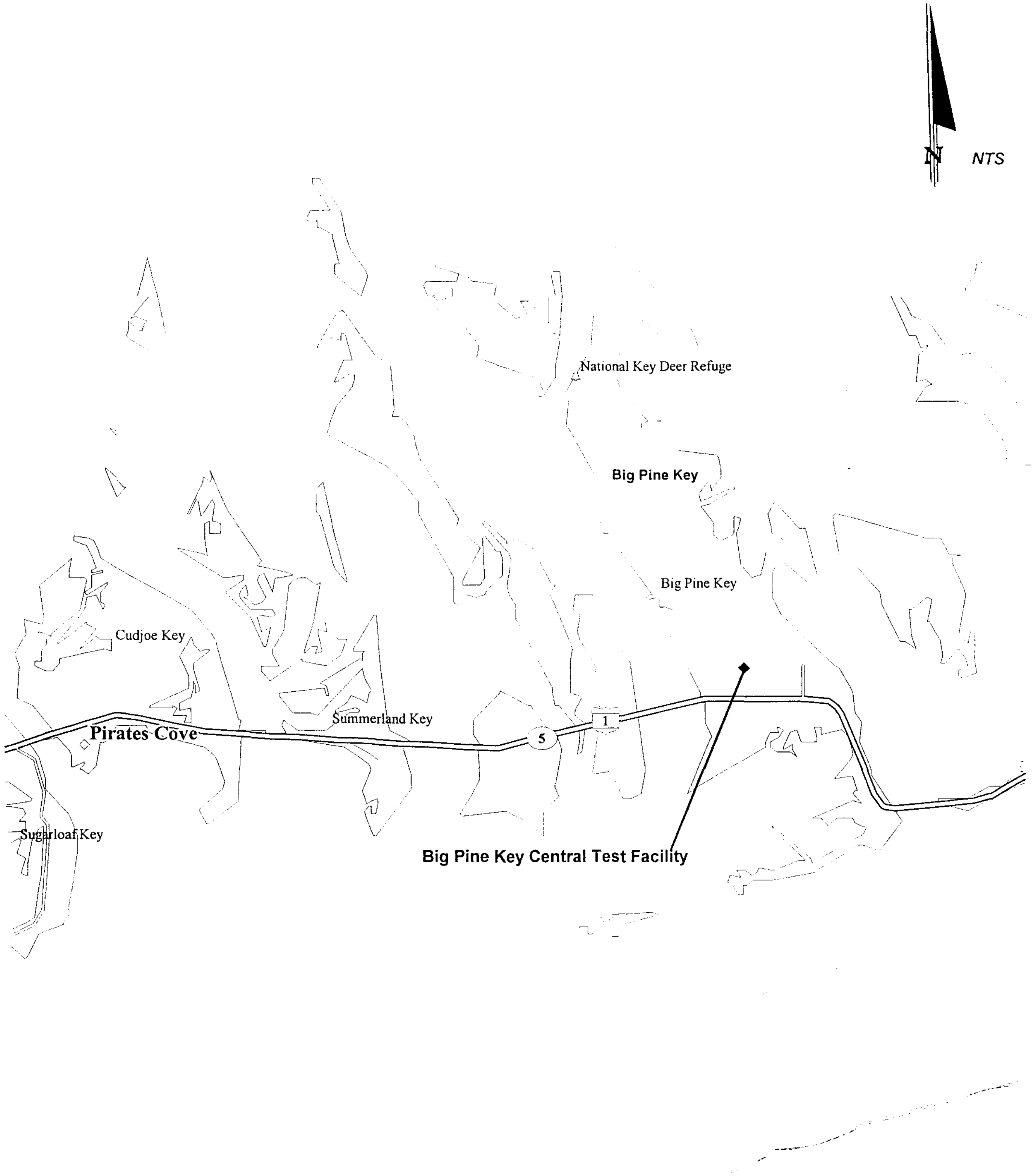
Wastewater generated by the BPKRP is domestic in nature, and is representative of other residential wastewater flows within the Florida Keys. Raw wastewater from the dormitories, kitchen, and laundry facilities flow to a lift station and is conveyed by forcemain to the wastewater treatment plant. The area needed for the test facility was available adjacent to the WWTP and a portion of the raw wastewater flow from the lift station could easily be diverted to the test facility.

4.2.2 Treatment Process Selection

A comprehensive survey to identify and evaluate various commercially available OWNRS was not part of this study. Numerous commercially available OWTS which offer various degrees of nutrient removal existed at the time of this project, but none which claimed to meet AWT effluent standards. Therefore, several unit processes for nitrogen and phosphorus removal as well as the known proprietary units were evaluated for consideration in the testing program.

Criteria used to select units included:

- Documented performance data demonstrating advanced treatment and nutrient removal capabilities;
- Reliable and consistent performance;
- Relatively passive operation requiring minimum operator intervention;
- Available in treatment capacities for single home use;
- Reasonable equipment, construction and operating costs;
- Use of locally available construction materials;
- Readily accepted by homeowners; and
- Willingness of manufacturer to participate in the project and furnish equipment.



Reference: DeLorme Mapping

Figure 4-1. Big Pine Key Central Test Facility Location Map

Of those systems reviewed, five units were selected for the demonstration project. These systems are briefly summarized below:

1. Conventional septic tank coupled with a recirculating sand filter (RSF) and an anoxic bio-filter (ABF).
2. Conventional septic tank coupled with subsurface drip irrigation (SDI) in porous media irrigation beds.
3. Bio-Microbics, Inc. FAST™ (Fixed Activated Sludge Treatment) system, a commercially available proprietary system.
4. Advanced Environmental Systems BESTEP-IDEA™ CFCR (Continuous Feed Cyclic Reactor) system, a commercially available proprietary system.
5. Klargester, Inc. Biodisc™ Rotating Biological Contactor (RBC), a commercially available proprietary system.

The selected systems were designed for advanced secondary treatment levels of BOD_5 and TSS, and limited nitrogen removal via nitrification/denitrification, or natural processes in the case of the SDI system. Only the Advanced Environmental Systems CFCR claimed phosphorus removal capabilities. Therefore, additional unit processes were chosen for phosphorus and nitrogen removal and were evaluated as treatment processes which could be added to these units. These included a chemical precipitation unit (CPU), engineered porous media intermittent filter beds with SDI, and a carbon tablet feeder/anoxic bio-filter for denitrification. The selected effluent disposal options evaluated were subsurface drip irrigation (SDI) beds with engineered porous media for phosphorus adsorption.

4.2.3 CTF Design, Construction, and Operation

Details of the CTF design can be found in the Engineering Design Report completed by Ayres Associates in November 1995. The construction drawings for the facility are included in Appendix A of this document. A brief summary of the CTF design and construction are presented here.

The CTF was designed to provide uniform wastewater loading to five wastewater treatment process trains simultaneously. Raw wastewater from the prison lift station was diverted to an influent mixing tank (IMT) at the CTF, as needed. This tank was a 750 gallon concrete tank with an electric mixer installed. Raw wastewater was pumped from this tank to small, elevated containers, or dose pots, at the head of each treatment train. Prior to, and during pumping, the mixer was run to mix the contents of the IMT so that a uniform raw wastewater was distributed to the dose pots. The dose pots were filled to a calibrated volume of 5 gallons at each dosing event, and pneumatically activated pinch valves at the bottom of each dose pot were then opened to allow each dose to flow by gravity to the treatment units.

Effluent from the treatment systems flowed to small effluent basins (approximately 20 gallons in size) which contained an effluent pump. These basins served as sampling basins for the treated wastewater. The effluent pumps were float/level activated and pumped the treated effluents back to the prison wastewater treatment plant.

Construction of the CTF began in July 1996 and included site preparation, pipe trenching and installation, treatment equipment installation and set-up, electrical wiring, and process control equipment and instrumentation installation and set-up. Construction was completed in early October 1996, and treatment system start-up occurred on October 16, 1996.

4.2.4 Wastewater Hydraulic Loading

Electrical instrumentation automatically controlled the wastewater loading process and also logged the dosing events. The loading schedule was programmed to simulate the diurnal wastewater flow characteristics of a single family residence, with peaks in the morning and early evening hours. Under normal operating conditions, forty dose pot volumes (5 gallons per dose) were loaded to each treatment train per day according to the schedule presented in Figure 4-2. This resulted in an average daily flow of 200 gallons per day to each treatment system, slightly higher than the estimated average flow for Keys homes. A float switch in each dose pot sent a signal to an event counter in the control panel so that the actual number of doses could be monitored. The facility was designed so that the flow could be adjusted for stress testing or other purposes.

4.2.5 Stress Loading Conditions

In addition to the normal loading conditions, the treatment units were subjected to stress loading conditions. The stress loading conditions included a vacation and wash day simulation, and were designed to evaluate the treatment performance under non-ideal conditions. The stress condition simulations were performed similar to the performance testing and evaluation methods outlined in *NSF Standard 40: Residential Wastewater Treatment Systems*. An explanation of each stress condition is provided below:

Vacation Stress: On the day the vacation stress was initiated, the systems were dosed at 65% of their daily hydraulic load. The dosing was then discontinued for 13 consecutive days while the process units remained operating. On the 14th day, normal daily dosing was resumed, with additional doses to simulate activities associated with returning from a trip. Sampling of each system was initiated on the 14th day.

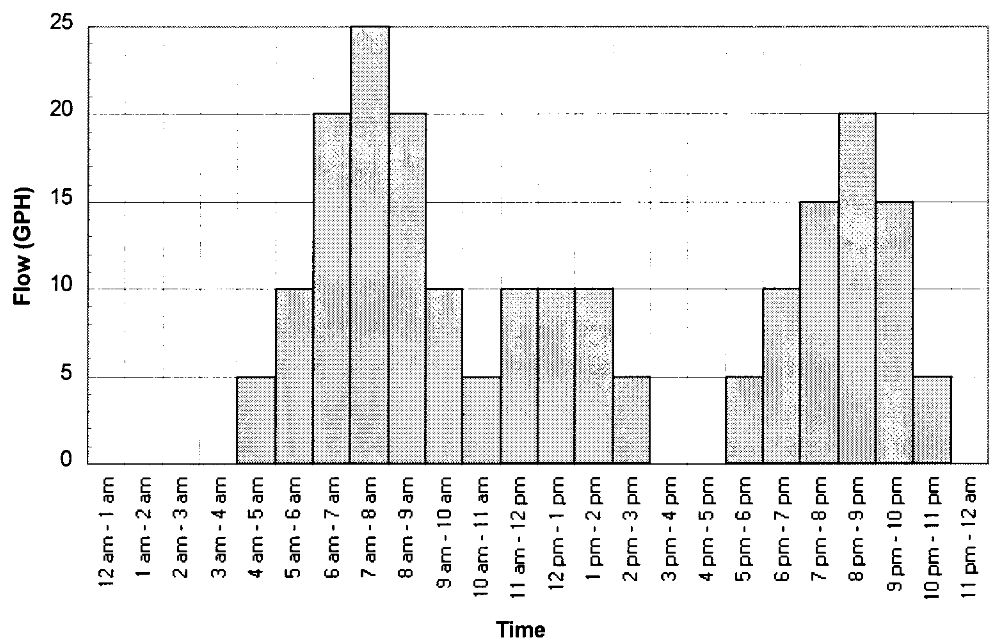


Figure 4-2. Daily Dose Schedule to Treatment Process Units (5 gallons per dose)

Laundry Day Stress: This stress loading consisted of two consecutive simulated wash days. During a wash day, the systems were loaded normally, but with the addition of 3 wash loads (3 wash cycles and 6 rinse cycles) within a 3 hour period each day. A wash load was simulated by adding 5 cups of detergent, containing phosphate, to the IMT and dosing each system 8 times per hour (40 gallons) This was repeated for a total of 3 loads to each system. Thus, each wash load consisted of an additional 40 gallons of wastewater being added to each system for a total additional wastewater loading of 120 gpd for each wash day. Sampling of each system was initiated after the second wash day loading.

4.3 Description of OWNRS Processes and Equipment

The treatment technologies evaluated in the OWNRS demonstration project included physical, chemical, and biological treatment processes.

No single treatment system was identified which provided AWT effluent levels for all parameters, so treatment technologies were combined to obtain better levels of treatment. Results for individual treatment units were monitored to be able to evaluate their performance alone as well as in combination with other processes. One "passive" technology stream utilizing a natural system and four "active" technology process streams were evaluated. A description of the five process streams and the unit processes involved with each follows. Figure 4-3 provides a schematic of the test facility and process streams monitored as part of this project.

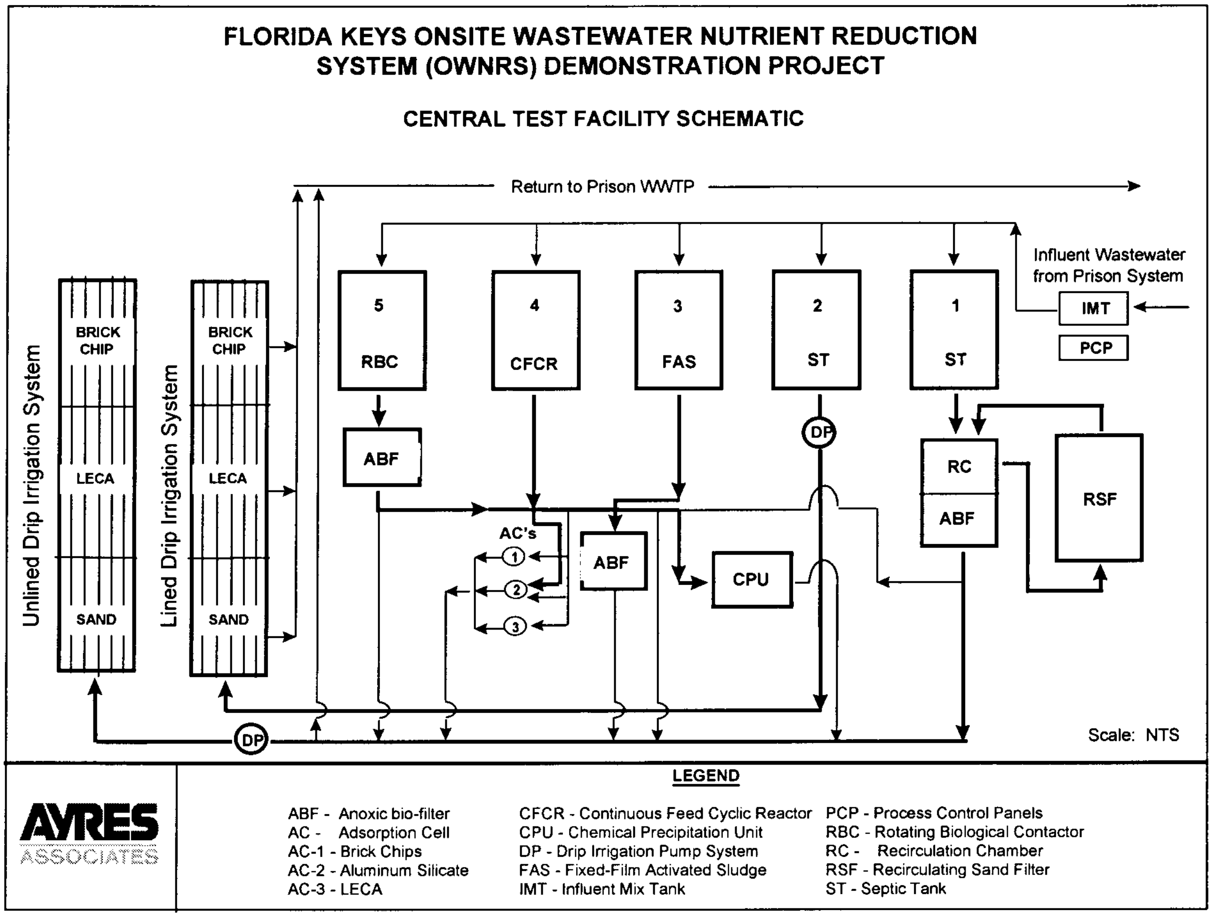


Figure 4-3. Central Test Facility Schematic

4.3.1 Process Stream 1 - Recirculating Sand Filter/Anoxic Bio-Filter/Drip Irrigation

Raw wastewater was discharged to a two-compartment, 1050 gallon precast concrete septic tank (ST-1). Septic tank effluent (STE) was discharged to the recirculation chamber (RC). A pump in the RC dosed the recirculating sand filter (RSF) at timed intervals (i.e., 6 minutes every hour). The filtrate drained back to the RC where it was either mixed with incoming STE or flowed into an anoxic bio-filter (ABF). This split was accomplished using a floating ball valve which closed the line to the RC when tank levels reached the desired level. Detailed drawings of the system are provided in Appendix A.

The RSF was constructed in a 2800 gallon precast concrete tank, 14.8 feet long by 7.7 feet wide (114 ft^2). The filter consisted of 24 inches of granular sand filter media underlain by a 12 inch gravel underdrain collection system. The sand filter media had an effective size of 0.75 millimeters (mm) with a uniformity coefficient of 1.6. Wastewater was distributed over the media from 15 microsprayers attached to a pressurized distribution system. The sand filter dosing was controlled by a timer and a series of float switches. The RSF was intermittently dosed at approximately 6 to 7 gallons per minute (gpm), on a 6-minute cycle every hour, which provided an approximately 3.5 to 1 recirculation ratio.

The ABF is an anoxic, attached growth biological unit process designed to provide additional removal of nitrogen by denitrification. Wastewater flowed horizontally through the ABF tank which was filled with Accu-PAC™ PVC media, and discharged by gravity to an effluent chamber (EC), which was used for sample collection and effluent disposal. During this study, the effluent from the EC was pumped to a subsurface drip irrigation bed for phosphorus removal and effluent disposal, but effluent water quality testing was performed on samples from the EC.

The drip irrigation bed was constructed by excavating 12 inches of the natural limerock and filling the excavation with selected porous media fill. The bed was then built up an additional 12 inches above grade for a total of 24 inches of porous media. Three treatment media were 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 clay bricks manufactured in North Carolina (Cherokee-Sanford Brick Co.). The LECA™ and crushed brick material were chosen based on phosphorus adsorption capacity reported in previous studies (Jensenn et al., 1994; Rubin, 1996).

The drip irrigation bed was 6 ft. wide by 32 ft. long and utilized a subsurface drip irrigation (SDI) system (AZTEX Products, Inc.) for effluent distribution to the root zone. The SDI bed was divided into three separate cells, one with each of the three media types. The SDI system consisted of fifteen 5/8-inch drip irrigation lines spaced on 4-inch centers. The effluent was discharged via in-line emitters spaced every two feet within the lines. Each emitter discharged at a rate of 0.6 gallons per hour (gph). Effluent that was not discharged from the emitters was returned to the septic tank influent side. A return flow of approximately 1 gpm was maintained to flush solids from the drip pipe.

Wastewater treatment in this system occurs through digestion and settling in the septic tank and physical, chemical, and attached growth aerobic biological processes in the RSF. Microorganisms which establish themselves on the sand media consume organic material in the wastewater and nitrify ammonia nitrogen to nitrate. Additionally, adsorption by the RSF media removes limited quantities of phosphorus. The nitrified RSF filtrate is mixed with anoxic septic tank effluent in the recirculation chamber, and denitrifying organisms convert nitrate to gaseous forms of nitrogen, which exit the system to the air. The effluent also undergoes further denitrification in the anoxic bio-filter if sufficient carbon is available to complete the process.

Further treatment occurs in the SDI bed following the ABF. Additional nitrification/denitrification can continue in the porous media of the SDI bed, and plant uptake of nitrogen can also further reduce total nitrogen levels discharged to groundwater. Phosphorus is reduced via plant uptake and adsorption onto porous media surfaces. Engineered media such as the LECA™ and crushed brick material have a high capacity for phosphorus adsorption relative to the sand typically used for drainfield construction in the Keys.

4.3.2 Process Stream 2 - Septic Tank/Lined Drip Irrigation Bed

This system utilized relatively passive technology and consisted of a 1050 gallon, 2 chamber precast concrete septic tank (ST-2) followed by a lined SDI bed. The STE was distributed to the root zone via a pressurized subsurface drip irrigation system provided by AZTEX Products, Inc., and was installed exactly like the drip bed described above, except this bed was lined to maintain saturation in the lower part of the bed.

The lined bed was also constructed with three separate porous media cells. Each cell contained one of the three porous treatment media; 1) locally available sand; 2) expanded clay aggregate from Norway, commercially known as LECA™; and 3) crushed brick material from clay bricks manufactured in North Carolina (Cherokee-Sanford Brick Co.). Each treatment media was hydraulically separated from each other and the groundwater by an impermeable liner. The liner maintained a one foot saturated zone to provide effluent storage and encourage evapotranspiration by plants. Effluent overflow from the lined beds was collected by a 4-inch drain running horizontally through the media that flowed by gravity into separate effluent chambers for each media type. The effluent from each media could then be sampled prior to its return to the prison WWTP. A drawing of the lined drip bed is provided in Appendix A and the drip irrigation equipment in Appendix B.

Preliminary reduction of nutrients and other parameters occurs by digestion and settling in the septic tank, but the majority of treatment occurs through physical, chemical, and biological treatment processes occurring in the lined irrigation bed and by plant uptake of nutrients. The effluent undergoes nitrification/denitrification in the drip bed and phosphorus adsorption by the porous media.

4.3.3 Process Stream 3 - Bio-Microbics FAST™/Anoxic Bio-Filter

The principle treatment unit in this system was a proprietary unit known as the Bio-Microbics FAST™ biological treatment unit. A schematic of the Bio-Microbics FAST™ system is provided in Appendix C.

The FAST™ treatment tank is separated into two chambers. The first chamber receives raw wastewater influent and provides primary treatment. Wastewater overflows via a 6-inch diameter hole 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 wastewater aeration.

This unit utilizes a fixed activated sludge (FAS) process, a combination of suspended growth and attached growth aerobic biological processes, for BOD removal and nitrification. Nitrified effluent is then recirculated and mixed with primary treated wastewater to promote denitrification. Treated wastewater then flows by gravity into an effluent chamber where it is pumped to an ABF treatment unit.

The ABF unit was designed to provide additional denitrification of the FAS effluent. No specific phosphorus removal process was included in this process stream. Effluent from the FAS unit could be directed to an engineered media SDI bed for phosphorus removal.

4.3.4 Process Stream 4 - Advanced Environmental Systems BESTEP

This system consisted of a proprietary treatment unit known as the AES BESTEP-IDEA™ system, an alternating aerobic/anoxic, suspended growth biological treatment process which operates as a continuous feed cyclic reactor (CFCR). A schematic of the AES BESTEP-IDEA™ is provided in Appendix D. 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 was 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.

The CFCR system operated on a 6-hour cycle and effluent was decanted four times a day at the end of each cycle. The 6-hour cycle started with an aeration phase which initiated BOD_5 oxidation and nitrification. A small mixer operated during the beginning of the aeration phase. The next phase was an anoxic period in which denitrification occurred. The aeration/mixing and anoxic phases are repeated during the cycle. The last aeration phase was then followed by an extended anoxic/settling/clarification period during which effluent is decanted. The next aeration period then began a new 6-hour cycle. This unit was designed primarily for nitrogen removal, but phosphorus removal is also possible if routine sludge removal is provided. This would require addition of a waste sludge tank to the system. Also, effluent from the system could be discharged to an engineered media SDI system for phosphorus removal.

4.3.5 Process Stream 5 - Klargester Biodisc/ABF

This system consisted of a proprietary treatment unit known as the Klargester Biodisc™, a rotating biological contactor (RBC). A schematic of the Klargester Biodisc™ system is provided in Appendix E. The RBC is an attached growth, aerobic biological treatment process which provides BOD and suspended solids removal. The Klargester Biodisc RBC also utilizes internal nitrified effluent recycle for denitrification. Effluent from the system was discharged to an ABF for additional denitrification.

The Klargester Biodisc RBC is contained in a three chamber fiberglass tank. Raw wastewater influent flowed into a primary settling area within the tank. The primary treated wastewater then flowed up into the secondary treatment area where the RBC media was located. The RBC was divided into three disk stages with eight plastic media disks in each stage. The wastewater flowed through each RBC stage in series and into a final settling chamber. A pump placed in a final settling zone recycles sludge and nitrified effluent to the primary tank every hour for thirty seconds at the flow rate of 10 gpm. The RBC effluent flowed by gravity to a separate ABF in a precast concrete tank, which contained submerged plastic filter media. A sump area at the end of the ABF collected the final effluent which was pumped back to the prison WWTP. No phosphorus removal mechanisms were included in this process stream; however, effluent from the system could be discharged to an engineered media SDI system for phosphorus removal.

4.3.6 Supplemental Treatment Processes

Since no single treatment unit was identified which provided AWT effluent levels for both nitrogen and phosphorus, several additional unit processes were evaluated at the CTF. These units were evaluated as supplemental treatment processes which could be combined with other units to provide additional nitrogen and/or phosphorus removal. These supplemental processes included the engineered media SDI beds discussed earlier, a chemical precipitation unit (CPU) for phosphorus removal, and a carbon tablet feeder/ABF for denitrification of nitrified effluents. The CTF was designed so that effluent from the five process streams described above could be routed to the supplemental processes for further treatment and evaluation.

Engineered Media Subsurface Drip Irrigation (SDI) Beds: The SDI bed described in Process Stream 1 with the RSF was designed as a phosphorus removal unit as well as an effluent disposal system. The SDI bed with the LECA™ or crushed brick media

(Cherokee-Sanford Brick Co.) could be added to any treatment unit for this purpose, and would also provide additional nitrogen removal.

Chemical Precipitation Unit: A Chemical Precipitation Unit (CPU) was designed and constructed to evaluate additional removal of phosphorus. The CPU utilized ferrous sulfate (OdoPhos™) as a precipitant to enhance the phosphorous removal capabilities of the system.

The CPU was used for physical/chemical removal of phosphorus. The process consisted of a chemical feeder, a mixing chamber with electrical mixer, and a settling chamber for the precipitated chemical sludge. The chemical feeder dosed the ferrous sulfate to the mixing chamber at the rate of 6 milliliters (ml) per minute. The dose timer was set up initially to provide a single dose of 90 ml per day, and was based on stoichiometry. The CPU effluent discharged to a sump tank and was returned to the WWTP equalization basin.

Carbon Tablet Feeder: The Carbon Tablet Feeder was designed to provide additional denitrification. Since the treatment units tested provided almost complete (<5 mg/L) CBOD removal, denitrification in the ABF units was limited by carbon availability. A proprietary NITELESS™ carbon tablet feeder by On-Site Wastewater Management, Inc., was included on an ABF unit to achieve further nitrogen removal by adding a source of carbon for further denitrification. The ABF operates as an anaerobic, attached growth biological process and consisted of a 750 gallon concrete tank in which wastewater flow was directed horizontally through AccuPac™ PVC media. The tablet feeder adds a biodegradable carbon in tablet form to the influent end of the ABF.

4.4 Investigative Materials and Methods

Several instruments for collecting data were employed during the course of this study. This equipment included data logging instruments which collect and store data at specified times as well as manual instruments used in measuring water quality, water flows, and energy use.

The data logging instruments included a remote data system for monitoring water table fluctuations in the lined beds, an evapotranspiration meter (ET) to measure the evaporation and plant transpiration rate of moisture from the soil, and a weather station to monitor onsite weather conditions. Other instruments used at the CTF included water testing meters and sample collection devices.

4.4.1 Weather Monitoring

A weather station was installed at the CTF to obtain onsite weather conditions. The weather station was equipped with a data logger that collected and stored data until it could be transferred to a computer. The weather station recorded rainfall, temperature, wind speed, and wind direction. Supplemental rainfall and temperature data was obtained from the U.S. Fish and Wildlife Service, National Key Deer Refuge, located on Big Pine Key. This supplemental weather data was used to replace data lost during power failures and also to compare data collected at the CTF with local data. Data was collected from October 1, 1996 to August 29, 1997.

4.4.2 Water Level Elevation Monitoring

Water levels in the lined SDI beds were collected both automatically and manually. A remote data system (RDS) recording water level monitor was placed in different observation ports during the project to monitor water level fluctuations in the lined SDI beds. The RDS was a data logging device designed specifically for measuring and storing water level information at user specified intervals; the stored data was transferred to a computer. The RDS was premarked with a calibration point that was adjusted to the top of casing for each observation port in which it was installed. By using the RDS, water level information was collected continuously from each lined bed. RDS information was collected from January 30, 1997 to August 29, 1997.

Manual readings of the water levels in the observation points were also recorded during site visits utilizing a manual water level indicator. The water level indicator was comprised of an aluminum reel with a 1/8" round polyurethane measuring cable attached to a stainless steel sensor. As the sensor was lowered into water, a light and buzzer indicated contact with the water surface. This measurement was read directly from the cable and recorded. Measurement of the water levels in the observation ports were collected from October 1996 to August 1997.

4.4.3 Evapotranspiration Monitoring

Evapotranspiration is the loss of water from the soil both by evaporation and by transpiration from plants during the growing season. In order to measure the amount of evapotranspiration occurring at the CTF, an automated atmometer was installed. The ETgage™ Model E was a covered ceramic evaporator that mimicked the solar energy absorption and vapor diffusion resistance of selected irrigated crops. The large central section of the instrument was a reservoir for distilled water. One inch evapotranspired from a crop corresponds to a water level drop of one inch in the reservoir. The evaporator drew water from an accurately calibrated glass vial. When the vial was empty, it was refilled from the reservoir through a solenoid valve. Each time the vial refilled an output pulse was generated to mark the event electronically. The evapotranspiration data was visually read and recorded from both an electronic counter and directly from a sight glass tube attached to the side of the instrument. These readings were collected during each site visit and the estimated amount of water evapotranspired from the soil was calculated in gallons per day.

4.4.4 Water Quality Field Testing

During each sampling event the physical characteristics of the influent and effluent wastewater streams were field measured for pH, conductivity, temperature, and dissolved oxygen. These readings were collected with the aid of equipment designed specifically for each of these parameters. Prior to each use the equipment was checked against known buffers and standards and calibrated as necessary. These measurements were collected and recorded during each sampling event throughout the project.

4.4.5 Wastewater and Effluent Sampling

Twenty-four hour flow composited wastewater samples were obtained from the various treatment units and the influent mixing tank. At each process stream effluent chamber (EC) a sampling port was installed to collect a flow-proportioned side stream aliquot sample for water quality analysis. Flow from the sampling ports were proportioned so a five gallon sample was collected over the 24-hour period. Samples were collected in five gallon carboys placed on ice in a cooler. The flow composited samples were used to evaluate the systems performance on a monthly basis. The sampling location points are shown on Figure 4-4.

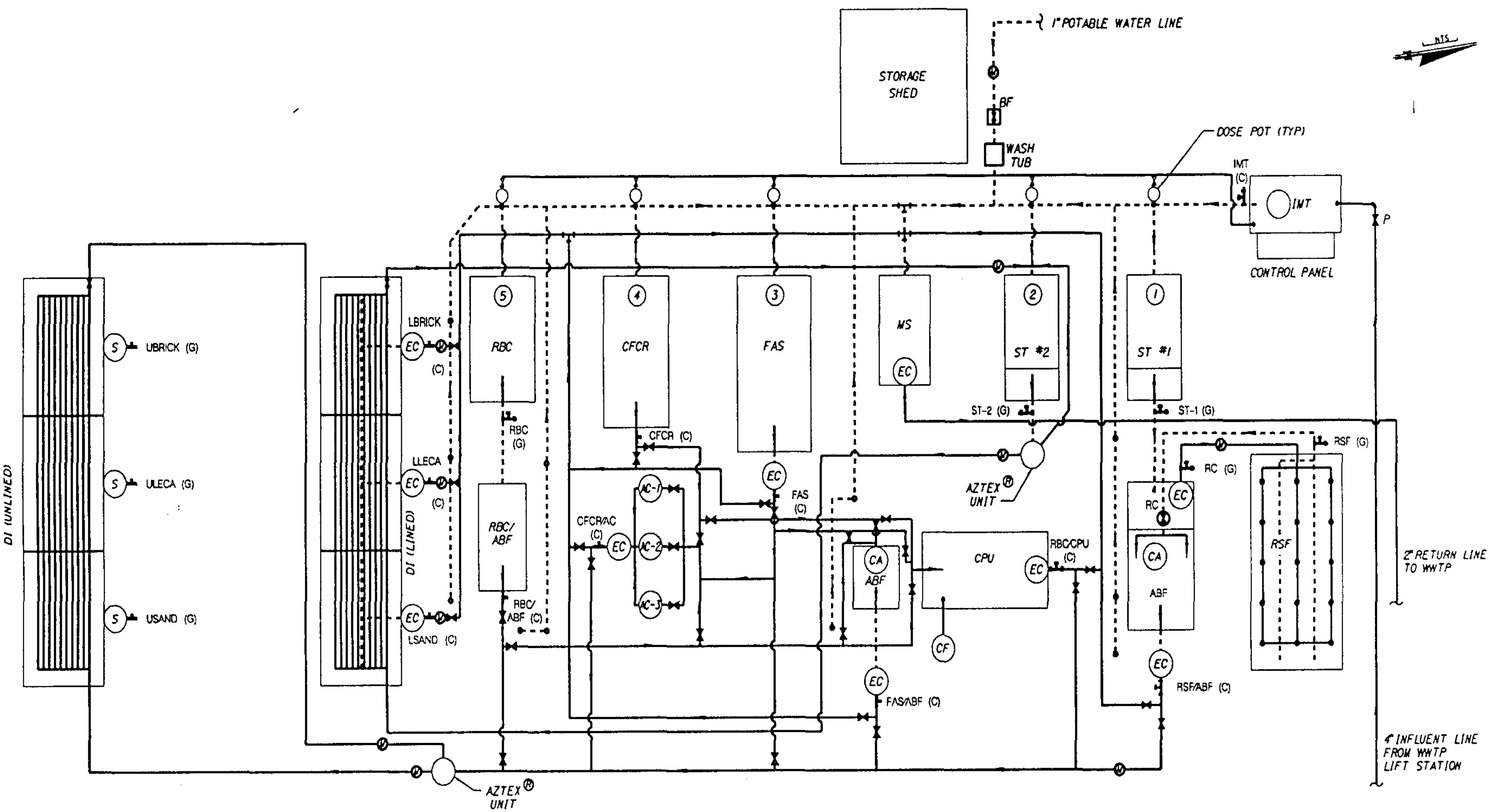
In addition, single grab samples were collected at various locations to evaluate individual unit processes. The grab samples were collected by 1) sample ports installed specifically for collecting samples; 2) transferring directly from the source by the use of a peristaltic pump, or, 3) the use of a dipper. The grab samples were also collected for comparison to the composite samples as quality assurance.

4.4.6 Water Quality Analyses

Water quality samples from the OWNRS treatment systems were collected on a monthly basis. Field measurements during the sampling events included pH, temperature, dissolved oxygen, and conductivity. The system performance samples collected were analyzed for some or all of the parameters listed in Table 4-1.

Table 4-1. Analytical Parameters, Method of Analysis, and Detection Limits.

Analytical Parameter	Method of Analysis	Laboratory Detection Limit (mg/L)
Biochemical Oxygen Demand (BOD_5)	SM 5210 B	1
Carbonaceous Biochemical Oxygen Demand ($CBOD_5$)	SM 5210 B	1
Chloride (Cl^-)	EPA 325.2	0.1
Ammonia Nitrogen (NH_3)	EPA 350.1	0.01
Nitrate-Nitrite Nitrogen (NO_2+NO_3)	EPA 353.2	0.01
Total Kjeldahl Nitrogen(TKN)	EPA 351.2	0.05
Orthophosphate (PO_4)	EPA 365.2	0.01
Total Phosphorus (TP)	EPA 365.2	0.03
Surfactants (MBAS)	SM 5540 C	0.05
Sulfate (SO_4)	EPA 375.4	2
Total Dissolved Solids (TDS)	EPA 160.1	10
Total Suspended Solids (TSS)	EPA 160.2	1
Volatile Suspended Solids (VSS)	EPA 160.4	1
Oil and Grease	EPA 413.1	2
Mixed Liquor Suspended Solids (MLSS)	SM 2540 D	1
Mixed Liquor Volatile Suspended Solids (MLVSS)	SM 2540 E	1
Fecal Coliform (colonies per 100 ml)	SM 9222A	1 colony/L



LEGEND

ST = SEPTIC TANK
RSF = RECIRCULATING SAND FILTER
ABF = ANOXIC BIO-FILTER
RC = RECIRCULATION CHAMBER
IMT = INFLUENT MIXING TANK
AC = ADSORPTION COLUMN
DP = DOSING POT
CPU = CHEMICAL PRECIPITATING UNIT
EC = EFFLUENT CLEARWELL

S = SAMPLE TANK
CA = CARBON ADDITION
CF = CHEMICAL FEED UNIT
RBC = ROTATING BIOLOGICAL CONTACTOR TREATMENT UNIT
FAS = FIXED-FILM ACTIVATED SLUDGE TREATMENT UNIT
CFCR = CONTINUOUS FEED CYCLIC REACTOR
MS = MASTER SUMP
AC-1 = BRICK CHIPS
AC-2 = ALUMINA SILICATE
AC-3 = LECA

• - 4" GRAVITY CLEANOUTS
SAMPLE PORT (C OR G)
- - - - GRAVITY LINE
—— - PRESSURE LINE
FLOW METER
2" BALL VALVE
RECIRCULATION VALVE
(C) - COMPOSITE SAMPLE
(G) - GRAB SAMPLE

REVISIONS

Date	By	Description	Date	By	Description
3/97	MBT	SITE PLAN REVISED			

	Names	Dates
Drawn by	MAN	2-97
Checked by	CGH	2-97
Designed by	MBT	2-97
Checked by	DLA	3-97
Approved by	MARK B. TYL	

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SEAL:

STATE OF FLORIDA
DEPARTMENT OF HEALTH AND REHABILITATIVE SERVICES

AYRES JOB NO. 30-0159.07 — CONTRACT NO. LP-988

SHEET TITLE: SAMPLE POINT LOCATION MAP — Figure 4-4

PROJECT NAME: FLORIDA KEYS OWNRS PROJECT CENTRAL TESTING FACILITY — Index No. NA

4.4.7 Quality Assurance/Quality Control (QA/QC)

Ayres Associates' Comprehensive Quality Assurance Plan (CompQAP) # 880993G was approved by the Florida Department of Environmental Protection (FDEP) for environmental monitoring and sampling projects. Sampling protocols for collection of soils, wastewater and groundwater samples, sample handling and shipping, and chain-of-custody procedures were conducted as outlined in this plan by Ayres Associates' field personnel.

All wastewater sampling and analyses were conducted in accordance with EPA Region IV and FDEP standard operating procedures.

As part of the water quality sampling QA/QC procedure, Ayres Associates performed quality control checks on a routine basis in accordance with 62-160, FAC. These QA/QC checks were obtained in order to gauge the accuracy and reliability of the analytical laboratory performing the analysis of the samples as well as a check on field procedures. These checks consisted of equipment blanks, duplicate samples, split samples, and spiked samples.

After field equipment was cleaned, rinsate water was collected as equipment blanks. The equipment blanks were analyzed for the same parameters as associated samples.

Duplicate samples were collected to measure the variability inherent in the sampling process, during each sampling event. Duplicate samples were collected by collecting water from the same container or in succession from the same wastewater source.

As a quality control check split samples were collected as a means of determining the variability between laboratories. Split samples were gathered by either collecting the sample from the same composite container, or by filling the first sample collection bottle half full and then filling a second bottle half full and alternating between the bottles.

Spiked samples were also used to determine the accuracy of the laboratory. Spiked samples with a known value of an associated parameter were delivered to the laboratory as a sample. The results of these samples were then compared to the anticipated results to aid in the determination of the quality of the laboratory results.

Prior to use, during each sampling event, field instruments were calibrated. During calibration procedures, solutions of a known value were used to adjust the accuracy of the field instruments. The instruments that were calibrated prior to use included the pH, conductivity, and temperature meter, and the dissolved oxygen meter.

5.0 TREATMENT PERFORMANCE RESULTS

5.1 Influent Wastewater Hydraulic Loading

The central test facility was activated on October 1, 1996 and monitoring continued until October 8, 1997 for a total of 372 days. The actual operation period was estimated at 323 days because of system downtime. The downtime was due to 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 number of doses were divided by the number of days the system was in operation. Based on this method, the average estimated daily loading to each treatment process stream was 189 gallons per day. The average hydraulic loading to the systems was thus slightly less than the design flow mainly due to system down time.

5.2 Influent Wastewater Quality Results

Twenty-four hour flow composited samples were collected from the influent mix tank (IMT) from November 1996 through August 1997. 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), volatile suspended solids (VSS), total dissolved solids (TDS), total Kjeldahl Nitrogen (TKN), nitrate + nitrite nitrogen (NO_2NO_3-N), ammonia nitrogen (NH_4-N), ortho phosphate (PO_4), total phosphorous (TP), chloride (CL^-), foaming agents (MBAS), fats, oils, and greases (FOG), and sulfate (SO_4). Results of the water quality analyses for the influent samples are provided in Table 5-1. The detailed analytical data are provided in Appendix F.

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 138, 117, 38.4, and 8.4 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.

5.3 Temperature, Precipitation, Evapotranspiration Monitoring

A data logging weather station was installed at the CTF site on November 17, 1996. Temperature and rainfall data were collected every hour and stored internally for downloading into a portable computer. These temperature and precipitation data are summarized in Appendix G.

Table 5-1. Summary of Influent (IMT) Water Quality Data.

Parameters (mg/L)[1]	No. of Samples	Mean	Std. Dev.	Range min. - max.
BOD_5	10	170	73.8	62 - 299
$CBOD_5$	10	138	60.1	59 - 220
TSS	12	117	92.1	17 - 345
VSS	6	122	107.2	17 - 310
TDS	7	360	28.7	318 - 404
TKN	12	38.4	10.7	19.2 - 62.5
NO_2NO_3-N	10	0.03	0.02	0.01 - 0.05
NH_4	12	30.5	8.30	18.9 - 50.8
PO_4[2]	10	5.49	1.78	3.24 - 9.30
TP[2]	12	8.39	5.79	4.32 - 26.00
CL^-	7	65.9	9.9	48 - 80
MBAS[2]	8	3.52	6.70	0.12 - 20.00
FOG	7	30.99	11.75	13.9 - 50.0
SO_4	7	74.34	19.03	49 - 105

(1) mg/L = milligrams per liter

(2) Maximum values are due to laundry loading stress event on 5/29/97

Supplemental weather data was obtained from the U.S. Fish and Wildlife Service, National Key Deer Refuge, Big Pine Key. These data were used to fill in the time period from October 1, 1996 through November 17, 1996, prior to the installation of the weather station. Weather data obtained from the U.S. Fish and Wildlife Service was also used to supplement data that was occasionally lost due to power outages.

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, 1997. January 1997 was unusually wet with 5.99 inches of rainfall. The wettest month during the study period was October 1996 with 8.64 inches of rainfall. The driest month was November 1996 with 0.29 inches of rainfall. The warmest month was July 1997 with an average monthly temperature of 87.7° Fahrenheit (F). The coldest month was January 1997, with an average monthly temperature of 71.8 °F.

Evapotranspiration (ET) was estimated at the CTF utilizing the ETgage™ and by water balance. The ETgage™ was installed at the north end of the lined SDI beds and readings began in October 1996. The time period from June 12, 1997 to July 16, 1997 indicated the highest ET rate of 0.1683 inches per day. The time period from July 18, 1997 to August 29, 1997 indicated the lowest ET rate of 0.0729 inches per day. The lower ET can be attributed to significant amount of rainfall over this period and high humidity.

ET values were also estimated for the SDI beds by calculating a water balance around the lined beds. Effluent discharge from the drip system plus rainfall amounts were included in flow to the beds. Any water discharged to the effluent chambers was subtracted from this amount, leaving an estimate of the water lost to ET. No water balance could be conducted on the sand media drip bed due to a leak in the effluent chamber. Based on the surface area of the drip beds, the ET rates in gallons per day were calculated. These values were compared to the values calculated from ETgage™ measurements.

The results of the ETgage™ and water balance ET calculations for the lined drip irrigation beds are summarized in Table 5-2. The estimated ET rates compared relatively well between the ETgage™ and the LECA™ drip bed water balance estimate. ET rates by these estimates were low, ranging from approximately 2 gpd to 9 gpd over the course of the study, with the higher values generally in the hot summer months. Substantially higher ET rates were estimated by a water balance on the crushed brick media, ranging from 2 gpd to 27 gpd. The crushed brick media was of significantly finer texture than the other media, with a much higher water holding capacity. This finer texture allowed more ET from the unsaturated zone and is thought to account for the ET difference between media.

Table 5-2. Comparison of Estimated Evapotranspiration Rates (gpd).

Date	ETgage™ Measurements (gpd)	Water Balance Calculations for Lined SDI beds (gpd)		
		Sand Media	LECA™ Media	Crushed Brick Media
July 18, 1997 to August 29, 1997	3.1	ND(1)	9.1	10.5
June 12, 1997 to July 18, 1997	7.2	ND	5.3	12.3
May 9, 1997 to June 12, 1997	6.3	ND	6.3	17.2
April 3, 1997 to May 9, 1997	6.5	ND	5.8	20.2
February 27, 1997 to April 3, 1997	6.2	ND	6.5	27.0
January 30, 1997 to February 27, 1997	4.6	ND	4.7	17.6
December 19, 1996 to January 30, 1997	3.5	ND	NM(2)	10.2
November 20, 1996 to December 19, 1996	4.3	ND	1.9	1.6

(1) ND - No data, leak discovered in effluent chamber

(2) NM - Not measured

5.4 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 five process stream effluents are provided in Table 5-3. For the lined bed SDI system (Process Stream 2), only the results of the crushed brick media (LBRICK) are reported here. As a benchmark, the treatment performance of the various units was compared to the Florida AWT standard of a 5, 5, 3, 1 mg/L monthly average for $CBOD_5$, TSS, TN, and TP, respectively.

5.4.1 $CBOD_5$ and TSS Reductions

The mean influent $CBOD_5$ concentration of 137.8 mg/L was reduced below the required AWT effluent standard of 5 mg/L by all systems. The mean effluent $CBOD_5$ concentrations ranged from 1.5 mg/L for Process Stream 1 (RSF-ABF) to 3.19 mg/L for Process Stream 4 (CFCR). Figure 5-1 shows the 95% confidence intervals for the $CBOD_5$ results by treatment unit. These data indicate the variability of the treatment units over the study period. A narrow 95% confidence interval, such as the RSF-ABF, indicates less variability in effluent concentrations and more consistent treatment, as compared to a wide 95% confidence interval.

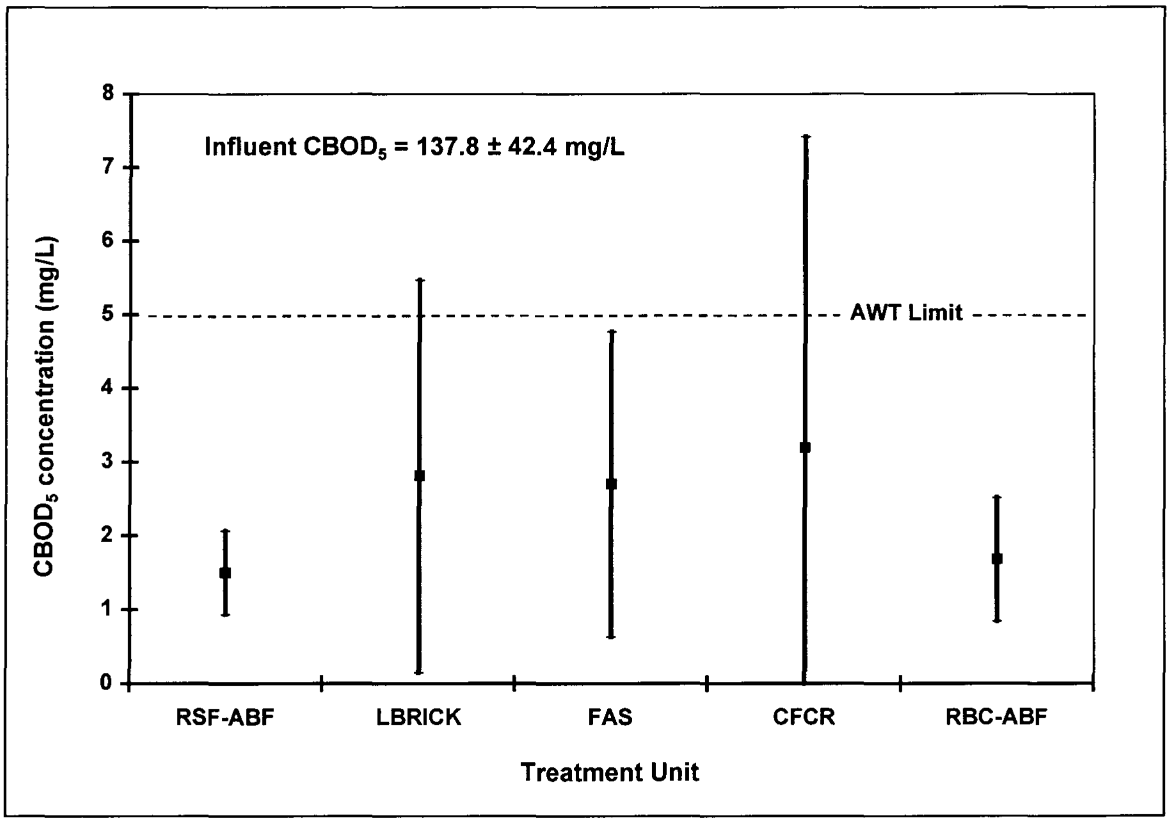


Figure 5-1. Effluent $CBOD_5$ Concentrations (mean ± 95% C.I.)

Table 5-3. Summary of Effluent Water Quality Data.

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

Total suspended solids (TSS) were removed effectively below 5 mg/L by the RSF-ABF, LBRICK, and FAS. Mean influent concentration of 117.5 mg/L was reduced to 2.25, 4.09, and 4.63 mg/L, respectively. Mean TSS effluent concentrations in the other two systems (CFCR and RBC-ABF) were 6.85 and 5.75 mg/L, respectively.

The results of the first quarter of operation for both the RBC and CFCR skewed the mean results. During the first quarter of operation, the CFCR had problems with the system wiring and the air compressor which resulted in high TSS. In addition, both systems had slow acclimation times during the first period. However, both systems stabilized over time and the TSS results for the last six sampling events were below 5 mg/L.

Figure 5-2 shows the 95% confidence intervals for TSS. Once again, these data show the treatment consistency of the RSF process.

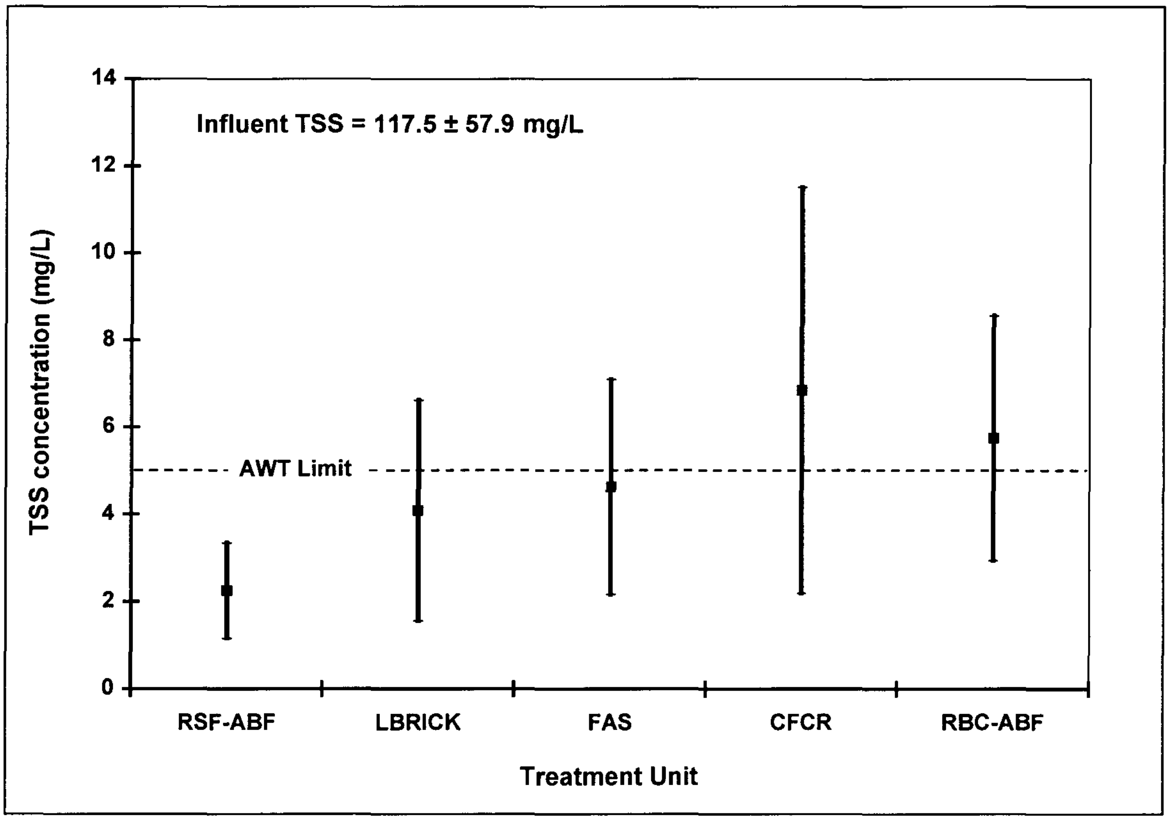


Figure 5-2. Effluent TSS Concentrations (mean ± 95% C.I.)

To determine when biomass levels were fully developed, the CFCR biomass was monitored by measuring settleable solids and mixed-liquor volatile suspended solids (MLVSS). Settleable solids were measured onsite using an Imhoff Cone. MLVSS samples were submitted for laboratory analysis. Table 5-4 shows the accumulation of solids in the system. These data indicate that the system did not reach expected design biomass solids concentrations. The manufacturer recommended operating at MLVSS levels of approximately 2,600 mg/L. Since biomass concentrations were still increasing at the end of the monitoring period, performance of the CFCR unit would likely increase once design biomass levels are reached.

Table 5-4. Summary of Settleable Solids and MLVSS Measured in the CFCR.

Sampling Date	Settleable Solids (ml/L)[1]	MLVSS (mg/L)
February 26, 1997	67	900
April 2, 1997	120	1120
April 23, 1997	130	1050
May 8, 1997	130	1055
May 21, 1997	NS[2]	1115
June 11, 1997	150	1285
July 17, 1997	250	1495

[1] ml/L = milliliters per liter

[2] Not sampled

5.4.2 Total Nitrogen and Total Phosphorus Reductions

Effluent quality for the nutrients nitrogen and phosphorus showed significantly more variation between processes. None of the five process streams met the AWT nitrogen standard of 3 mg/L. The influent total nitrogen (TN) concentration was 38.4 mg/L. The FAS and RBC-ABF systems performed best for nitrogen removal, with mean effluent TN values of 11.0 mg/L and 12.5 mg/L, respectively. 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 15.5 mg/L for CFCR to 21.2 mg/L for the SDI system with crushed brick media (LBRICK). Figure 5-3 presents the 95% confidence intervals for the nitrogen data. The FAS treatment 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 AWT effluent standards.

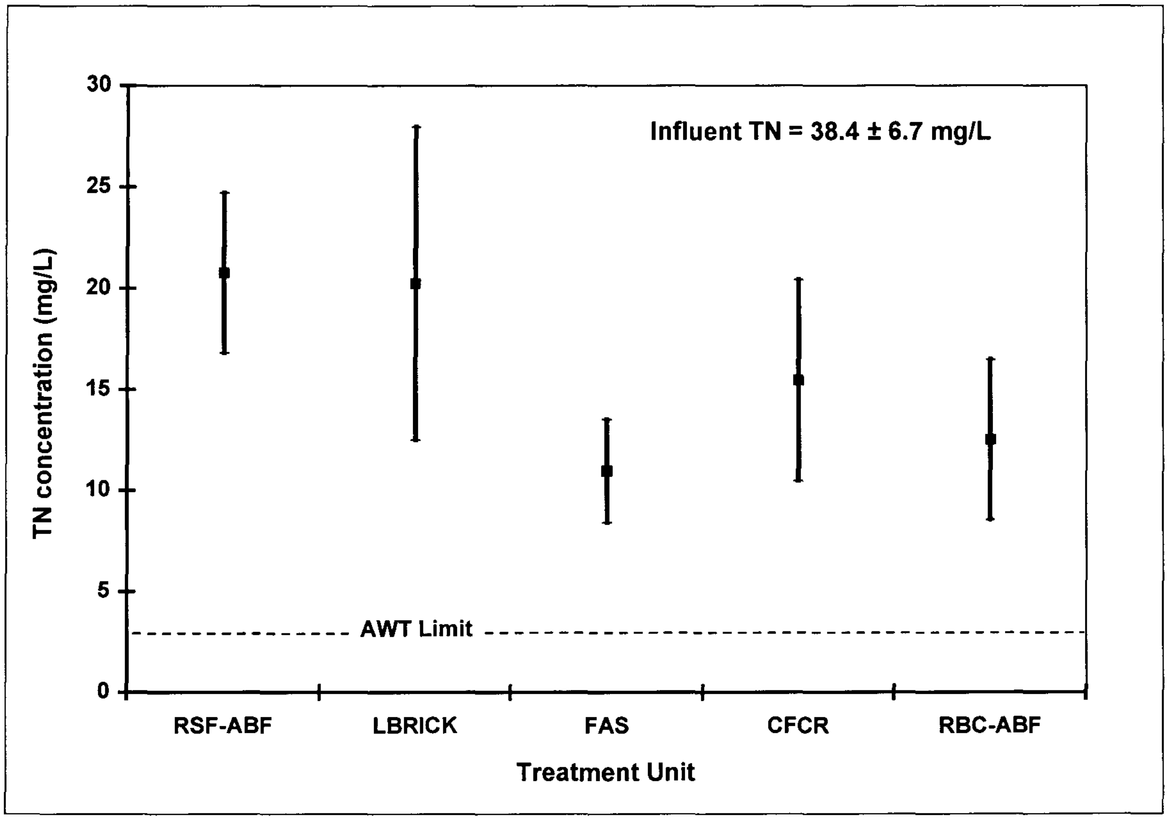


Figure 5-3. Effluent TN Concentrations (mean ± 95% C.I.)

The total phosphorus influent concentration of 8.39 mg/L was reduced to 0.6 mg/L by the SDI system (Process Stream 2) with the crushed brick media. This was the only process stream which met the AWT effluent TP standard of 1 mg/L. Significant removals were also observed in the RSF-ABF system, where the TP concentration was reduced to 1.8 mg/L. It remains to be seen, however, how long these removal efficiencies will last. Once the media adsorption sites reach capacity, breakthrough of phosphorus at higher concentrations may occur. All other process streams reduced the total phosphorus concentration to values from 4.67 mg/L to 6.24 mg/L. Figure 5-4 presents the 95% confidence intervals for total phosphorus. The crushed brick media SDI bed provided the most consistent TP removal over the study period.

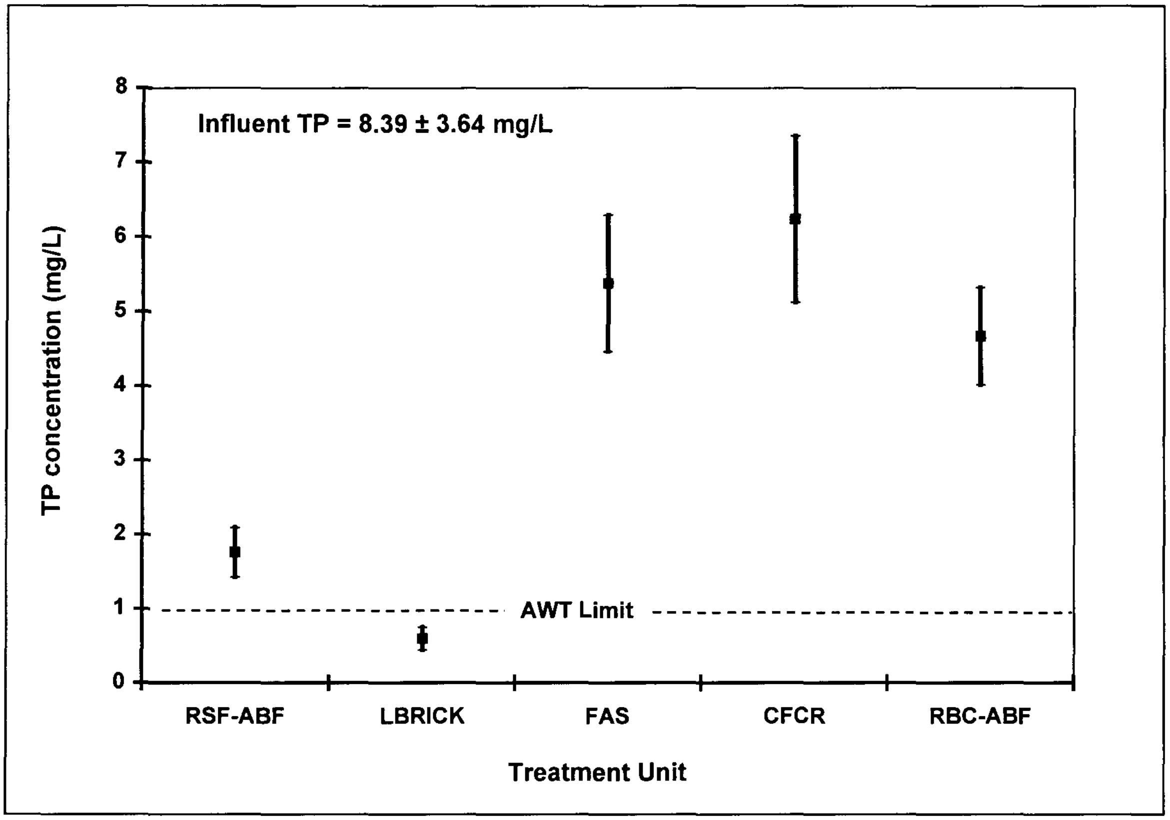


Figure 5-4. Effluent TP Concentrations (mean ± 95% C.I.)

5.5 Supplemental Unit Process Performance

Several supplemental unit processes were tested which could be added to treatment systems to improve nutrient removal. These systems included a carbon tablet feeder/ABF combination, a chemical precipitation unit (CPU), and engineered media subsurface drip irrigation (SDI) beds.

Carbon Tablet Feeder/ABF: The carbon tablet feeder/ABF was added to the FAS unit to increase denitrification of the effluent. Unfortunately, the carbon tablet feeder was a prototype unit and malfunctioned during the study. Therefore, the ABF was only able to achieve minor additional denitrification of the FAS effluent, averaging only 1.3 mg/L total nitrogen less than the FAS effluent alone (9.7 vs. 11.0 mg/L). Since the FAS effluent CBOD averaged less than 3 mg/L, insufficient residual carbon for more complete denitrification existed in the ABF tank following the FAS. Further modification and study of the carbon feeder are ongoing at the CTF.

Chemical Precipitation Unit (CPU): Effluent from the RBC/ABF unit was routed to a CPU utilizing ferrous sulfate as a precipitant. The CPU was able to reduce the TP effluent levels to below 1 mg/L provided sufficient precipitant was dosed to the system. The actual dose volume of ferrous sulfate (OdoPhos™) required to achieve the AWT level of 1 mg/L was estimated to be 270 ml/day, and was determined by increasing the ferrous sulfate dose until TP concentrations dropped below 1 mg/L. The actual dose volume required was significantly higher than that calculated from stoichiometry. The dose volume will vary for each system depending on operating conditions and wastewater compositions. Based on this dose volume it was estimated that 26 gallons per year of OdoPhos™ would be required. It was not possible to collect or measure the sludge volume produced during the short operating period of this study, but sludge production will be measured in the future. Using a dose rate of 270 ml/day, a TP influent concentration of 6 mg/L, and an effluent concentration of less than 1 mg/L, the estimated sludge volume was calculated at 0.07 pound per day, or 25.6 pounds per year. Based on a sludge solids concentration of 5%, this would amount to approximately 65 gallons of chemical sludge per year. This iron-phosphate sludge would have to be disposed of properly, presumably outside the Keys, to permanently remove the phosphorus from the Keys watershed.

Subsurface Drip Irrigation (SDI) Beds: The water quality results from the lined, engineered media SDI beds are presented in Table 5-5. The effluent from the septic tank (ST-2) is shown for comparison, as this was the influent to the drip irrigation beds. Mean $CBOD_5$ concentrations were reduced below the required 5 mg/L by all three media. $CBOD_5$ effluent concentrations from sand, LECA™, and crushed brick (Cherokee-Sanford Brick Co.) media were 2.1, 2.6, and 2.8 mg/L, respectively.

Total suspended solids were also effectively removed by the SDI beds. The effluent TSS concentrations from the LECA™ and crushed brick media were 3.79 and 4.09 mg/L, respectively. The sand media TSS concentration averaged 12.2 mg/L, but fines from the sand were noticed in several samples and were the suspected cause of the higher TSS concentration. Volatile suspended solids (VSS) concentrations from the sand media averaged 6 mg/L.

None of the SDI beds showed significant removal of total nitrogen from the influent. The mean influent TN concentration of 34.5 mg/L was reduced to 21.2 mg/L (crushed brick), 23.0 mg/L (LECA™), and 22.7 mg/L (sand), respectively, a 35 to 40 percent reduction by the SDI beds.

The crushed brick media (LBRICK) consistently reduced the total phosphorus influent concentration of 6.04 mg/L to 0.6 mg/L, below the Florida AWT Standard of 1 mg/L. The sand and LECA™ media reduced the TP concentration to 3.6 and 1.31 mg/L, respectively. The large particle size of the LECA™ media appeared to limit the phosphorus capacity of the media in the field, since lab testing showed the LECA™ capacity to be equal to or greater than that of the crushed brick. It is suspected that using a finer textured LECA™ media would result in significantly improved TP removal.

Table 5-5. Summary of Engineered Media SDI Bed Water Quality Data.

Parameters	Statistics	Influent (mg/L) ST-2 (grab)[1]	Engineered Media SDI Bed Effluent Concentrations (mg/L)		
			Sand (composite)	LECA™ (composite)	Crushed Brick (composite)
$CBOD_5$	Mean	49.04	2.07	2.65	2.81
	Range[2]	28.0 - 92.4	1.0 - 6.15	1.0 - 13.0	1.0 - 14.4
	Std. Dev.	19.9	1.83	3.76	4.04
	n[3]	9	8	10	11
TSS	Mean	25.92	12.2	3.79	4.09
	Range	11 - 42	1 - 44	1 - 12	1 - 11
	Std. Dev.	9.32	12.58	3.29	3.83
	n	12	10	12	11
TN	Mean	34.51	22.74	23.00	21.15
	Range	20 - 42	9.36 - 40.95	3.30 - 34.75	3.0 - 44.79
	Std. Dev.	7.90	9.87	9.41	11.27
	n	10	9	10	11
TP	Mean	6.04	3.60	1.31	0.60
	Range	3.68 - 8.90	0.88 - 9.90	0.72 - 1.80	0.34 - 1.20
	Std. Dev.	1.39	2.40	0.31	0.23
	n	11	10	12	11

(1) Grab or composite are sampling collection methods
(2) Range = minimum to maximum values
(3) n = number of samples

In summary, the engineered media (LECA™ and crushed brick) SDI beds performed well for phosphorus removal. Although the life of these media for TP removal in the field is unknown, laboratory batch testing suggests beds the size of those tested at the CTF (32' x 6' x 2') may provide phosphorus removal for 10 years or more at typical residential wastewater flows (200 gpd). Thus, engineered media SDI beds could be added as an effluent disposal option to any of the other unit processes to achieve additional nitrogen removal, and phosphorus removal to AWT levels.

5.6 Treatment Unit Stress Testing

Vacation Stress: On April 23, 1997 at 2:00 p.m., wastewater influent to the five process streams was shut off to initiate the vacation stress simulation. Wastewater dosing to the treatment systems was then discontinued for 13 consecutive days. Power to the systems was not interrupted during this period. On May 7, 1997, wastewater influent to the systems was re-established and an additional 100 gallons (20 doses) was supplied to each system. Twenty-four hour flow composited samples were initiated at this time and collected the following day.

Table 5-6 summarizes the results of the samples collected immediately following the simulated vacation period. Influent concentrations of $CBOD_5$, TSS, TN, and TP were 220 mg/L, 170 mg/L, 39.02 mg/L, and 7.10 mg/L, respectively, immediately following the vacation period. The influent $CBOD_5$ and TSS values were slightly higher, and the TP and TN values similar to the study averages for influent wastewater. $CBOD_5$ effluent concentrations ranged from 1.00 mg/L to 2.80 mg/L for the five treatment systems, indicating no reduction in treatment due to the simulated vacation period. TSS effluent concentrations were also similar to the study averages, except Process Stream 2 (SDI-crushed brick) showed a slightly higher TSS level. Total nitrogen effluent concentrations actually improved somewhat for Process Streams 1 and 2, and were similar for the other systems. Total phosphorus effluent concentrations were also similar to study averages. In summary, the simulated vacation period had little effect on treatment performance of the various systems studied at the CTF.

Table 5-6. Effluent Quality Results For Vacation Stress Testing (mg/L).

Parameter	Influent Wastewater (IMT)	Process Stream 1 (RSF-ABF)	Process Stream 2 (LBRICK)	Process Stream 3 (FAS)	Process Stream 4 (CFCR)	Process Stream 5 (RBC-ABF)
$CBOD_5$ (mg/L)	220 (137.8 ± 60.13)	1.00	1.00	1.00	2.80	1.00
TSS (mg/L)	170 (117.5 ± 92.09)	1.00	11.00	5.50	7.50	4.00
TN (mg/L)	39.02 (38.45 ± 10.70)	14.46	20.00	5.00	23.80	10.20
TP (mg/L)	7.10 (8.39 ± 5.79)	1.90	0.51	6.10	8.00	3.90

Note: The statistical values in ( ) are the study mean ± standard deviation for the influent wastewater.

Laundry Day Stress: The laundry stress test was conducted on two consecutive days. During a laundry day stress test, the systems were loaded normally with the addition of 3 wash loads (3 wash cycles and 6 rinse cycles) within a 3 hour period each day. Flow composited sampling was initiated on the second laundry day.

The results of the laundry day stress testing are summarized in Table 5-7. During the laundry day stress test, influent wastewater concentrations of $CBOD_5$, TSS, TN, and TP were 130 mg/L, 80 mg/L, 44.01 mg/L, and 26.00 mg/L, respectively. The $CBOD_5$ and TN influent values were similar to study averages while the TSS influent values were slightly lower. Influent total phosphorus values were three times higher than the study average due to the addition of phosphate detergent to the IMT during this test. $CBOD_5$ and TSS effluent concentrations were below AWT effluent standards for all systems for the laundry day samples. Total nitrogen effluent concentrations ranged from 13.2 mg/L to 26.47 mg/L, with all systems except Process Stream 4 (CFCR) exhibiting higher TN values than the study average. Total phosphorus effluent concentrations ranged from 0.68 mg/L to 9.9 mg/L for the five process streams. Phosphorus effluent concentrations did not increase much due to the increased phosphate load from the simulated laundry events. Effluent from Process Streams 3, 4, and 5 were slightly higher than the study mean effluent concentrations.

Table 5-7. Effluent Quality Results for Laundry Day Stress Testing (mg/L).

Parameter	Influent Wastewater (IMT)	Process Stream 1 (RSF-ABF)	Process Stream 2 (LBRICK)	Process Stream 3 (FAS)	Process Stream 4 (CFCR)	Process Stream 5 (RBC-ABF)
$CBOD_5$ (mg/L)	130 (137.8 ± 60.13)	1.00	1.20	1.00	1.80	1.80
TSS (mg/L)	80 (117.5 ± 92.09)	1.00	1.00	2.00	3.00	1.00
TN (mg/L)	44.01 (38.45 ± 10.70)	26.47	25.10	14.40	13.20	16.70
TP (mg/L)	26.00 (8.39 ± 5.79)	1.70	0.68	8.70	9.90	5.90

Note: The statistical values in ( ) are the study mean ± standard deviation for the influent wastewater.

In summary, the simulated laundry day loading had no effect on effluent $CBOD_5$ and TSS concentrations, but increases in TN and TP effluent concentrations were experienced for several systems.

5.7 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 5 mg/L were observed in all systems except the CFCR and RBC-ABF systems, which averaged TSS effluent concentrations of 6.85 mg/L and 5.75 mg/L, respectively.

None of the systems were able to produce average total nitrogen concentrations close to 3 mg/L, as required by the AWT effluent standards. 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. Addition of a supplemental carbon source prior to an ABF unit or additional recycle of wastewater between unit processes could accomplish additional denitrification. However, it appears unlikely that TN levels of 3 mg/L would be accomplished by the biological treatment units alone.

Phosphorus removal below the 1 mg/L AWT Standard was observed only by the crushed brick media SDI bed and the chemical precipitation unit. Other adsorption media may also be available which provides similar performance in the SDI process.

In summary, it appears that a combination of unit processes would be required to achieve onsite wastewater treatment performance which approaches the AWT effluent standards. A biological treatment system which incorporates nitrification/denitrification and discharges to an engineered media drip irrigation bed should meet the AWT standards for $CBOD_5$, TSS, and TP, and produce an effluent with TN concentrations less than 10 mg/L. With process optimization and/or the addition of supplemental carbon, such a system could produce effluent close to the AWT nitrogen standard (3 mg/L), as measured immediately below the SDI bed.

6.0 OWNRS OPERATION AND MAINTENANCE

The 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 one year monitoring period. The units were generally operated and maintained in accordance with the manufacturer's recommendations, or based on experience with similar systems.

6.1 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.

Operational inspections were conducted on a monthly basis during this study to become familiar with each system and determine the operational requirements of each unit process. Since the treatment units were designed to operate with little time and effort, it was anticipated that monthly operational monitoring would not be required in the field. Based on our experience with the systems and manufacturer's recommendations, semi-annual operational monitoring is recommended unless treatment performance falls below permit levels, in which case additional O&M would be required. Operation and maintenance should be conducted by a licensed operator with additional training by the system manufacturer or engineer.

A set of recommended operational activities was prepared based on the experience with the treatment systems and review of the manufacturer's installation guidelines, operation manuals, and sales information. The list was also presented to the equipment manufacturers to obtain their input. A summary of semi-annual and annual O&M activities for the systems studied is presented in Table 6-1. In addition, an estimate of time to perform the activities is presented.

Table 6-1 provides only the recommended O&M activities for each system. It should be noted that each units performance and operation and maintenance requirements will vary with individual home wastewater characteristics and additional maintenance visits may be required from time to time due to equipment or parts failure. Therefore, the O&M time ultimately required will also vary accordingly.

Table 6-1. Summary of OWNRS Operation and Maintenance Activities.

System	Activity Performed	Semi-annual	Annual	Estimated Time to Perform Activity Per Visit
RSF	Inspect recirculation pump operation, high water alarm system, and float operation.	X	X	10 min.
	Inspect sand filter surface.	X	X	10 min.
	Observe sprayer operation. Clean spray heads. Flush out distribution lines.	--	X	10 min.
	Record operational data (pump run time, dosing meter). Compare data to past records.	X	X	15 min.
	Calibrate pump and recirculation ratio.	--	X	20 min.
	Check sludge depth in septic and recirculation tanks.	--	X	10 min.
SDI	Inspect irrigation pump operation, high water alarm system, and return flow from irrigation beds.	X	X	15 min.
	Increase return flow and pressurize lines to flush out emitters and dripper lines.	--	X	15 min.
	Clean effluent screen in septic tank and filter cartridges in SDI pump unit.	--	X	20 min.
	Check pressure differential across dripper line. Adjust.	--	X	10 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.
	Record operational data (flow meters and pump timers). Measure return and forward flow rates. Compare data to past records.	X	X	15 min.
FAS	Check sludge depth, primary tank.	--	X	10 min.
	Check inspection port for aeration and blower screen. Clean filter.	X	X	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.
CFCR	Check timer clock and decant pump operation.	X	X	10 min.
	Check alarm system and float operations.	X	X	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.
	Wash off control floats and decant float.	--	X	10 min.
	Clean air compressor filter and effluent screen from flow inducer tube.	--	X	15 min.
RBC	Remove cover, check disk operation and biomass growth.	X	X	15 min.
	Check sludge recirculation pump in secondary tank and recycle dipper bucket.	X	X	15 min.
	Remove surface scum from primary tank.	--	X	10 min.
	Check sludge depth in primary and secondary tanks.	--	X	20 min.
ABF	Check biomass growth and dissolved oxygen levels in the tank.	X	X	15 min.
ABF/ Carbon	Check biomass growth and dissolved oxygen levels in the tank.	X	X	15 min.
	Check operation of carbon addition unit.	X	X	10 min.
	Record amount of carbon remaining. Refill carbon source.	X	X	20 min.
CPU	Inspect mixer operation and dosing level of precipitant. Check chemical quantity.	X	X	20 min.
	Check chemical sludge depth.	X	X	10 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.

Other O&M activities anticipated for the treatment systems include:

- 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.

Effluent quality monitoring is currently not required under compliance codes. However, a minimum level of testing is recommended to ensure treatment performance. For most systems this should consist of semi-annual effluent water quality sampling for AWT parameters at a minimum.

6.2 OWNRS Energy Consumption Results

Standard home electric meters were installed on each process stream at the CTF to measure energy consumption rates. 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 6-2.

Table 6-2. Treatment Process Power Consumption and Cost Data.

Observation Date	Process Stream 1 (RSF)	Process Stream 2 (SDI)	Process Stream 3 (FAS) (2) Period 1	Process Stream 3 (FAS) (3) Period 2	Process Stream 4 (CFCR)	Process Stream 5 (RBC)	Chemical Precipitation Unit	Drip Irrigation Bed
Number of Days in Monitoring Period	322	322	217	105	322	322	----	----
Net Electric Use (kW-hrs)	937	587	3003	903	987	831	----	----
Average Daily Electric Use (kW-hrs/Day)	2.9	1.8	13.8	8.6	3.1	2.6	0.19(4)	1.8(5)
Average Daily Electric Cost ($/Day) (1)	$0.29	$0.18	$1.38	$0.86	$0.31	$0.26	$0.02	$0.18

(1) Average Daily Electrical Cost Calculated on $0.10/kW-hr.
(2) The Bio-Microbics FAST unit blower and air distribution system was modified on 5/16/97. The number of days in first monitoring period was 217.
(3) Modified Bio-Microbics System ran for 105 days.
(4) Electric use based on manufacturer's literature.
(5) Electric use based on Process Stream 2.

Net power use for the five process streams was monitored for a period of 322 days. The average daily power use ranged from 1.8 kW-hr/day for the SDI (Process Stream 1) to 13.8 kW-hr/day for the FAS (Process Stream 3). However, the blower system for the FAS unit was changed during the study which reduced its power use to 8.6 kWh/day. Energy use for the supplemental treatment equipment was estimated using manual calculations which considered the mechanical horsepower and efficiencies of the motors. Electric use for the anoxic bio-filters and carbon addition units was less than one cent per day and was not included in these calculations.

6.3 OWNRS Chemical/Material Consumption Results

The chemical precipitation unit (CPU) and the ABF with carbon addition were the only processes tested that required chemical addition. OdoPhos™ (ferrous sulfate containing 0.5 lb. Fe^{2+} per gal.) supplied by U.S. Filter was used as the precipitant in the CPU for phosphorus precipitation. An application rate of 270 milliliters (mL) per day (or 16.2 g Fe^{2+} per day) was required to achieve 1 milligram per liter (mg/L) or less of total phosphorus in the effluent. This value was greater than that required based on stoichiometry alone, and was determined by increasing the OdoPhos™ dose until phosphorus concentrations fell below 1 mg/L. The CPU at the Central Test Facility was equipped with a standard 55-gallon storage container and dosing system. Price quotations from the supplier for OdoPhos™ ranged from $3.95 per gallon for a 55-gallon supply to $0.34 per gallon for bulk rate (5000 gallon truck loads not including freight costs). The bulk rate was used to determine the annual chemical costs for the CPU under the assumption that wastewater operators would store OdoPhos™ if a demand were to be created.

No chemical consumption data was collected for the carbon tablet feeder due to malfunction of the feeder.

The phosphorus adsorption media within the SDI beds was assumed to require periodic replacement, although no phosphorus breakthrough was noted during the study. The sand used has the most limited adsorption capacity of the media and was not considered as a feasible SDI media for phosphorus removal. The other two media tested, crushed brick (Cherokee-Sanford Brick) and LECA™ , showed significant capacity for phosphorus adsorption. Laboratory batch testing of these media showed similar results, but the crushed brick media performed better in the SDI beds. The finer texture of the crushed brick media is the suspected reason for this and it is anticipated that LECA™ of similar particle size would perform as well. Given the testing results, these two media were considered as feasible treatment systems for phosphorus removal in SDI beds. Because of the limited long term field test data available, the media lifetime expectancies were estimated from the batch tests. Based on laboratory batch test results the adsorption capacity of both media was estimated at between 0.025 and 0.05 lbs. phosphorus per 100 lbs. media. Batch adsorption test results generally under-estimate the field capacity for phosphorus due to the additional phosphorus removal from plant uptake and precipitation reactions with the media. Based on these assumptions, it was concluded that an SDI bed could reasonably be designed for single family homes to provide phosphorus removal for 10 years. For the purpose of this report, the replacement costs for the media was thus based on a 10 year life.

7.0 OWNRS COST EVALUATION

An objective of the OWNRS Demonstration project was to estimate annual costs for the OWNRS studied. These costs include capital or construction costs and operation and maintenance costs. The costs for these items are developed in this section. The costs are annualized so the treatment system costs can be compared based on the estimate of their total annual cost.

7.1 Capital Cost Evaluation

The capital equipment costs for the various OWNRS processes were estimated based on quotes obtained from equipment manufacturers and suppliers. Installation and construction cost estimates were obtained from verbal quotes from contractors located in the Florida Keys and from actual costs associated with the construction of the Big Pine Key OWNRS Central Testing Facility. All cost estimates are planning level estimates and are provided in 1998 dollars. Actual cost for any individual OWNRS in the Keys will be very site specific. Provided below is a list of assumptions and criteria used in developing the OWNRS capital costs:

- Treatment system sizes are based on single family home systems and 500 gallons per day (gpd) hydraulic capacities.
- A lump sum labor and equipment rate for a two-man crew with backhoe was estimated at $900 per day. General laborers and wastewater operators, and electrician billing rates per hour were estimated at $30 and $60, respectively.
- Permitting and operating fees were obtained from Chapter 64E-6, FAC, effective March 3, 1998.
- Tank, piping, pump, and other miscellaneous costs were obtained from various local suppliers.
- Capital cost estimates are planning level estimates and include a 20% contingency.

The cost for effluent disposal was included with each OWNRS construction cost. The disposal method included an SDI bed with engineered media, which also provided the phosphorus removal for the system. The following assumptions were used in estimating the SDI system costs:

- Subsurface drip irrigation (SDI) beds are sized at 8 foot (ft) by 32 ft by 2 ft deep with an engineered media. It is assumed that if approved as treatment alternatives, there would be an increase in demand for materials not readily available such as LECA™ and crushed brick (Cherokee-Sanford Brick Co.) media. Suppliers would respond by purchasing bulk quantities and storing the materials, similar to handling of sand media currently. This would cause the alternative media to achieve economies of scale and become more price competitive.

- The costs for LECA™ and crushed brick media were very similar, so a budgetary cost of $50 per ton was assumed for each. This cost includes delivery to the Keys.

A summary of capital costs for the OWNRS alternatives are provided in Table 7-1. Detailed capital cost estimates for the alternatives are provided in Appendix H. Costs for the other supplemental treatment processes tested are provided in Appendix I. The supplemental processes included an anoxic bio-filter (ABF) with carbon addition, SDI with engineered media, and chemical precipitation unit (CPU). These costs are provided so that the supplemental processes could be considered for addition to other treatment units or for retrofit of existing systems.

Table 7-1. Summary of Capital Costs(1).

OWNRS Description	Estimated Capital Costs (1998 $) with SDI Effluent Disposal
1. Recirculating Sand Filter (RSF) w/ SDI bed(2)	$17,414
2. Septic Tank w/ SDI bed	$7,872
3. Bio-Microbics FAST w/ SDI bed	$11,412
4. Continuous Feed Cyclic Reactor AES-BESTEP w/ SDI bed	$11,832
5. Rotating Biological Contactor (RBC) w/ SDI bed	$11,832

(1) Costs include all equipment and installation costs and a 20% contingency.
(2) SDI system tested was AZTEX Products, Inc., Model 100

The costs ranged from $7,872 (ST/SDI) to $17,414 (RSF). The ST/SDI process was the lowest because it did not include a biological nitrification/denitrification treatment unit associated with it.

Estimated capital costs for the supplemental treatment units were $3,720 for ABF with carbon, $5,412 for SDI with engineered media and $5,784 for the CPU, and also include a 20% contingency.

7.2 Operation and Maintenance Costs

Annual costs associated with the operation and maintenance (O&M) of the various alternatives are developed in this section. O&M activities were estimated based on review of the manufacturer's literature and experience at the Big Pine Key Demonstration facility, as described in Section 6.0. O&M costs include semi-annual operational visits, annual effluent monitoring, miscellaneous annual repair costs, energy, chemicals and operating permit costs. In addition, annual costs for mechanical equipment and media replacement, and residuals disposal costs were estimated for each alternative.

All cost estimates were prepared in 1998 dollars. Provided below is a list of assumptions and criteria used in developing the annual O&M costs:

- Operational visits are planned semi-annually and include routine system inspections and performance monitoring. One sample for annual effluent quality testing is assumed and is included in the permit and monitoring fee. It should be noted that additional effluent sampling may be desired, or required, if performance does not meet standards.
- A combined operation/maintenance visit is conducted on an annual basis. Additional labor time was added during this annual site visit to conduct preventive maintenance activities. O&M requirements vary according to the system but a minimum level of effort is required to maintain system performance.
- The O&M activities and planned site visits are based on the minimum requirements to maintain system performance and enforce the manufacturer's standard warranty contract. Additional O&M costs could occur at sites with higher than normal flows or strength.
- Annual operational labor costs are estimated between $150 and $200 depending on system complexity. A cost of $50 was added for miscellaneous repair parts and materials. Maintenance labor rate was estimated at $30 per hour.
- Energy costs were calculated using an electricity cost of $0.10 per kilowatt-hour (kW-hr) and the energy use from Section 6.0.
- Annualized costs were estimated for replacement of mechanical equipment including pumps, blowers, and air compressors. 10-year life cycles were estimated for this mechanical equipment.
- The SDI adsorption media was included in the replacement costs. The SDI media adsorption capacity was estimated from laboratory batch tests and field experience, and was estimated at 10 years. Therefore, adsorption media replacement was estimated every 10 years. Labor and material costs are included in the replacement costs. Also included as a residual disposal fee was a $250 fee for spent SDI adsorption media disposal after 10 years.
- Septic tanks were estimated to require primary sludge removal every 5 years. Aerobic biological treatment units were estimated to require primary and/or activated sludge removal every 3 years, based on manufacturer's recommendations.
- A residual disposal fee of $250 was estimated for primary and/or biological sludge removal from the treatment systems. The fee was based on quotes obtained from local contractors.

A summary of annual operation and maintenance costs for the OWNRS alternatives is provided in Table 7-2. Detailed O&M costs for each alternative are provided in Appendix H.

The estimated O&M costs included operational and maintenance labor costs, annual energy costs, chemical and equipment and media replacement costs. The total annual O&M costs for the five OWNRS tested ranged from $1,044 for the septic tank/SDI to $1,507 for the FAS/SDI (1998 $).

7.3 Summary of Annual Costs

A summary of the capital and annual O&M costs for the OWNRS are presented in Table 7-3. The annual capital costs were calculated based on amortization of capital costs for 20 years at 6 percent interest.

These capital and O&M costs were combined to obtain a uniform annual cost for comparison of OWNRS alternatives. Also included is a unit cost in dollars per thousand gallons ($/1000 gal) of treated wastewater capacity. The unit cost was obtained by dividing the uniform annual cost by the annual treated wastewater volume based on 500 gpd flow.

Uniform annual costs (UAC) for the OWNRS alternatives ranged from $1,730 for the septic tank/SDI to $2,841 for the RSF/SDI. These costs are very high if considered on a per home basis. In comparison, uniform annual cost for a conventional mounded OWTS in the Keys has been estimated at approximately $600 per year (Ayres Associates, 1998). In addition, the estimated UAC for the OWNRS exceeds the total per equivalent dwelling unit (EDU) cost estimate for collection, treatment, and disposal presented in the Draft Marathon Facilities Plan for a regional collection system and wastewater treatment plant (CH2M Hill, 1996).

Unit costs for treatment and disposal ranged from $9.71 to $15.57 per 1000 gal for the OWNRS alternatives. These costs are more reasonable and compare favorably to the unit costs projected in the Draft Marathon Facilities Plan for a collection system and wastewater treatment plant.

The reason for the discrepancy between comparisons of uniform annual cost and unit cost lies in the treatment capacity of the small onsite treatment units. The treatment capacity of most commercially available onsite treatment units is 500 gpd, and they are therefore capable of handling the flow from several EDUs in the Keys. Therefore, they are much more cost effective if evaluated on a $/1000 gal basis than an annual cost per EDU basis when the treatment systems are dedicated to one home. If a mechanism could be developed for utility ownership and operation of the OWNRS to serve multiple

Table 7-2. OWNRS Estimated Annual O&M Cost.

OWNRS Description	Operational Labor Costs	Annual Energy Costs[1]	Chemical Costs	Annual Permit Fee	Maintenance Labor	Maintenance Repair Costs	Annualized Replacement Costs [2]	Annualized Residual Disposal Costs [3]	Subtotal	20 % Contingency	Total Annual Costs
1. Recirculating Sand Filter (RSF) w/ SDI	$ 200.00	$ 171.55	-	$ 200.00	$ 120.00	$ 50.00	$ 297.34	$ 63.33	$ 1,102.22	$ 220.44	$ 1,322.66
2. Septic Tank w/ SDI	$ 200.00	$ 65.70	-	$ 200.00	$ 120.00	$ 50.00	$ 170.78	$ 63.33	$ 869.81	$ 173.96	$ 1,043.77
3. Fixed Activated Sludge (FAS) w/ SDI	$ 200.00	$ 379.60	-	$ 200.00	$ 120.00	$ 50.00	$ 208.73	$ 97.50	$ 1,255.83	$ 251.17	$ 1,507.00
4. Continuous Feed Cyclic Reactor (CFCR) w/ SDI	$ 200.00	$ 178.85	-	$ 200.00	$ 120.00	$ 50.00	$ 223.91	$ 97.50	$ 1,070.26	$ 214.05	$ 1,284.31
5. Rotating Biological Contactor (RBC) w/ SDI	$ 200.00	$ 160.60	-	$ 200.00	$ 120.00	$ 50.00	$ 210.62	$ 97.50	$ 1,038.72	$ 207.74	$ 1,246.46
Minimum	$ 200.00	$ 65.70	-	$ 200.00	$ 120.00	$ 50.00	$ 170.78	$ 63.33	$ 869.81	$ 173.96	$ 1,043.77
Maximum	$ 200.00	$ 379.60	-	$ 200.00	$ 120.00	$ 50.00	$ 297.34	$ 97.50	$ 1,255.83	$ 268.89	$ 1,507.00
Average	$ 200.00	$ 191.26	-	$ 200.00	$ 120.00	$ 50.00	$ 222.28	$ 83.83	$ 1,067.37	$ 213.47	$ 1,280.84

(1) Annual cost based on electricity rate of $0.10 per kW-hr
(2) Replacement costs include equipment and SDI media
(3) Disposal costs include spent SDI media and residuals

homes, they would be significantly more cost effective when compared to other collection and treatment alternatives.

Table 7-3. OWNRS Estimated Capital and Annual O&M Cost.

OWNRS Description	Total Capital Costs(1)	Annualized Capital Cost(2)	O&M Costs(1)	Uniform Annual Cost	Unit Cost $/1000 gal.
1. Recirculating Sand Filter (RSF) w/ SDI	$ 17,414.40	$ 1,518.54	$ 1,322.66	$ 2,841.20	$ 15.57
2. Septic Tank w/ SDI	$ 7,872.00	$ 686.44	$ 1,043.77	$ 1,730.21	$ 9.48
3. Fixed Activated Sludge (FAS) w/ SDI	$ 11,412.00	$ 995.13	$ 1,507.00	$ 2,502.13	$ 13.71
4. Continuous Feed Cyclic Reactor (CFCR) w/ SDI	$ 11,832.00	$ 1,031.75	$ 1,284.31	$ 2,316.06	$ 12.69
5. Rotating Biological Contactor (RBC) w/ SDI	$ 11,832.00	$ 1,031.75	$ 1,246.46	$ 2,278.21	$ 12.48

(1) Construction costs and annual O&M costs include a 20% contingency.

(2) Annualized costs were based on amortization of capital costs over 20 years at an interest rate of 6.0%.

8.0 INDIVIDUAL HOME SYSTEM DEMONSTRATIONS

A secondary objective of the Florida Keys OWNRS Demonstration Project was to evaluate relatively passive nutrient removal systems at typical Florida Keys home sites. This was accomplished by installing landscape irrigation systems at three different homes. The home sites were used to determine operation and maintenance requirements at actual homes, retrofit requirements, reliability and homeowners acceptance. The treatment performance of landscape irrigation systems was tested at the Big Pine Key CTF, and are reported in Section 5.0. This section provides a summary of the individual home demonstrations.

8.1 Site Selection

Subsurface drip irrigation systems were installed at three individual homes in the Lower Keys (Figure 8-1). They were selected from 29 potential candidates identified through applications submitted to Monroe County Public Health Unit. Selection was based on household demographics, water use rates and practices, lot layout, location of utilities, landscaped areas, natural water features, and plumbing schematics. Field visits were conducted to review the homes and document the layout. Three home sites were selected based on these reviews. A summary of each site is presented below.

Home Site 1 was a single family home with two adults and five children located on Sugarloaf Key, Florida. The home had three bedrooms and two bathrooms, and was on a public water supply. The lot measured 105 feet by 120 feet and the home was located approximately 30 to 40 feet from a canal. It is unknown when the home was constructed, but it appeared to be less than 15 years old.

Home Site 2 was a single family home with two adult residents, located on Sugarloaf Key, Florida. Typically, there were one to two additional adults visiting for extended durations. The home had 4 bedrooms and 3 bathrooms, and was served by a public water supply. The property measured 120 feet by 100 feet with the house sitting approximately 50 feet from Bow Channel. The home was constructed in approximately 1950 and the current residents have lived there since 1972.

Home Site 3 was a single family home with two adults and one child located on Big Pine Key, Florida. The home had three bedrooms and two bathrooms and had a cistern, which supplied water to the home. The lot size is 200 feet by 195 feet and was not located adjacent to any water bodies. The home was constructed in 1995.

Reference: DeLorme Mapping

Figure 8-1. Individual Homesites Location Map

8.2 Process Selection and Description

Subsurface drip irrigation (SDI) systems installed in landscape beds were selected because of their simplicity, availability, affordability, and the passive nature of their operation. In addition, landscape SDI systems provided beneficial re-use of wastewater effluents. The treatment performance of the drip irrigation system was evaluated at the Central Testing Facility (Process Stream 2).

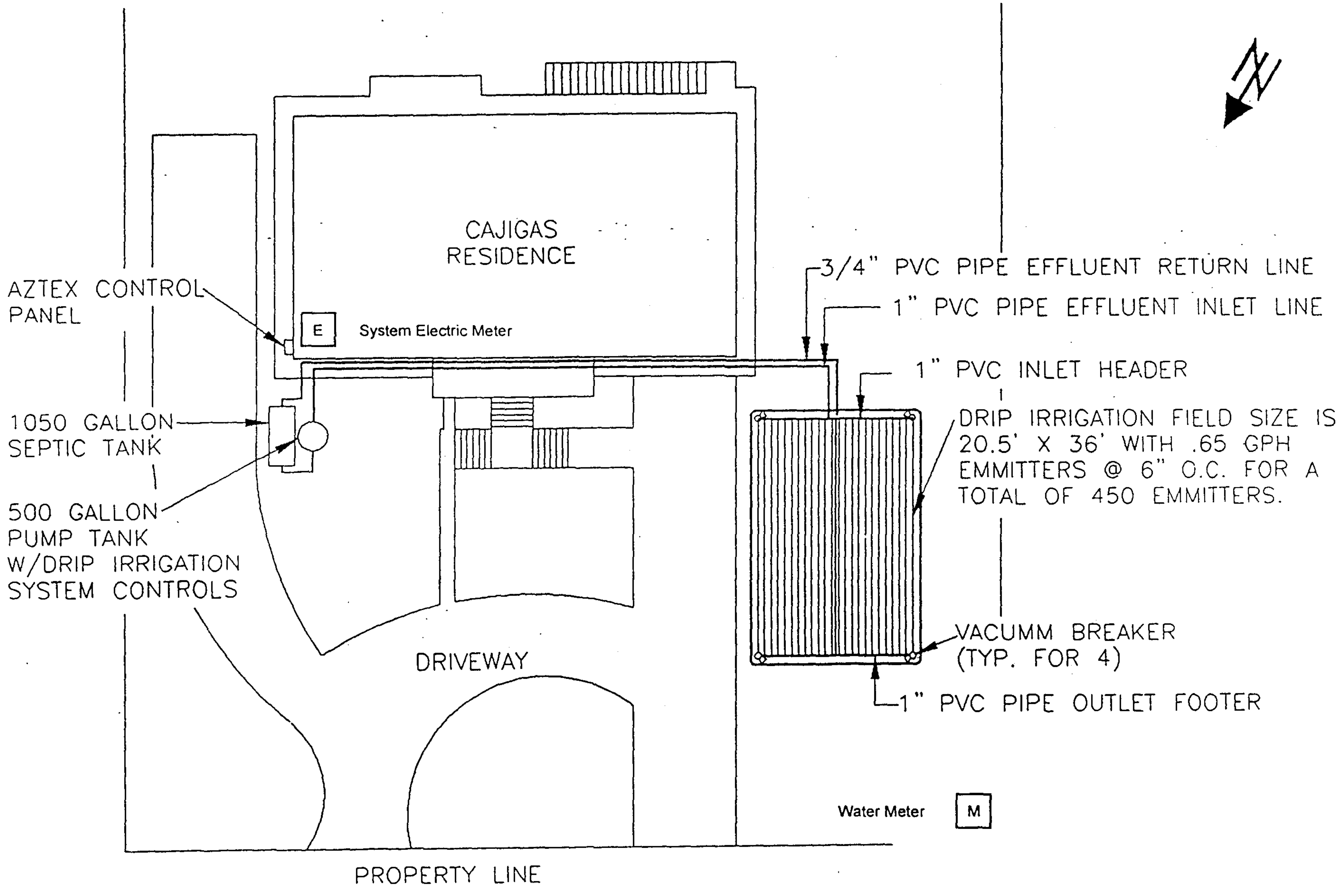
The design of the three individual home SDI systems were similar with the exception of Home Site 3, which included an aerobic treatment unit (ATU) prior to the SDI bed. Wastewater from each home drained into a conventional 1050-gallon septic tank. Septic tank effluent (STE) flowed by gravity into a 500-gallon holding tank, where the pump system is located. At Home Site 3, the STE flowed to an ATU manufactured by Clearstream™ Products, then to the 500-gallon pump tank. The STE, or ATU effluent, was then distributed to a 36-foot long by 20-foot wide raised irrigation bed via pressurized subsurface drip irrigation tubing. The bed was constructed using a locally available silica sand. STE that was not discharged was returned to the influent side of the septic tank. The system process mechanisms are the same as those described in Section 4.3.1. The drip irrigation system equipment was a commercially available unit manufactured by AZTEX Products, Inc.

8.3 Individual Home System Design and Construction

Based on the manufacturer's recommendation, Ayres Associates completed the design of the individual home demonstration systems. The treatment systems were designed in accordance with the OWTS standards of Chapter 10D-6, FAC, which were in place in 1996.

A local contractor, under the supervision of Ayres Associates and the DOH, constructed the individual home systems. Construction of the home systems was completed in July 1996. The systems at Home Sites 1 and 2 were retrofitted with the SDI system. The Home Site 3 system was installed at a new home. All of the homes were constructed on stilts, or with a crawl space, which made access to the plumbing of these homes fairly easy.

A single raised bed SDI design was used at each of the homes. The beds were constructed by excavating to a depth of 18 inches below grade. The excavations were then filled with silica sand and mounded to 12 inches above the existing grade. The drip tubing was placed on the mound and assembled and was then covered with St. Augustine sod. Layouts of the three home sites are provided as Figures 8-2 through 8-4.



AYRES ASSOCIATES

Figure 8-2. Home Site 1 SDI System Schematic

Scale: NTS

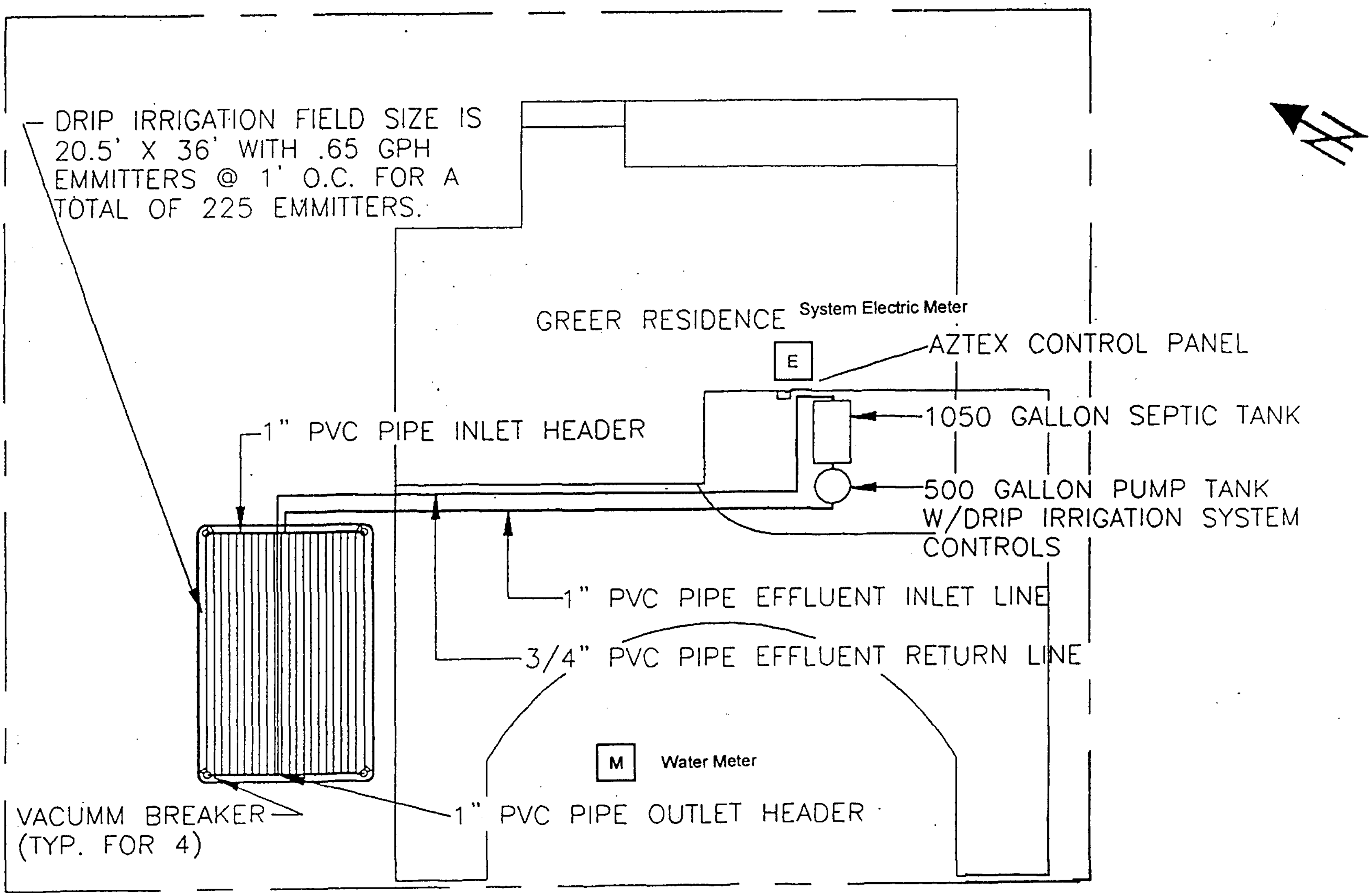


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Figure 8-3. Home Site 2 SDI System Schematic

Scale: NTS

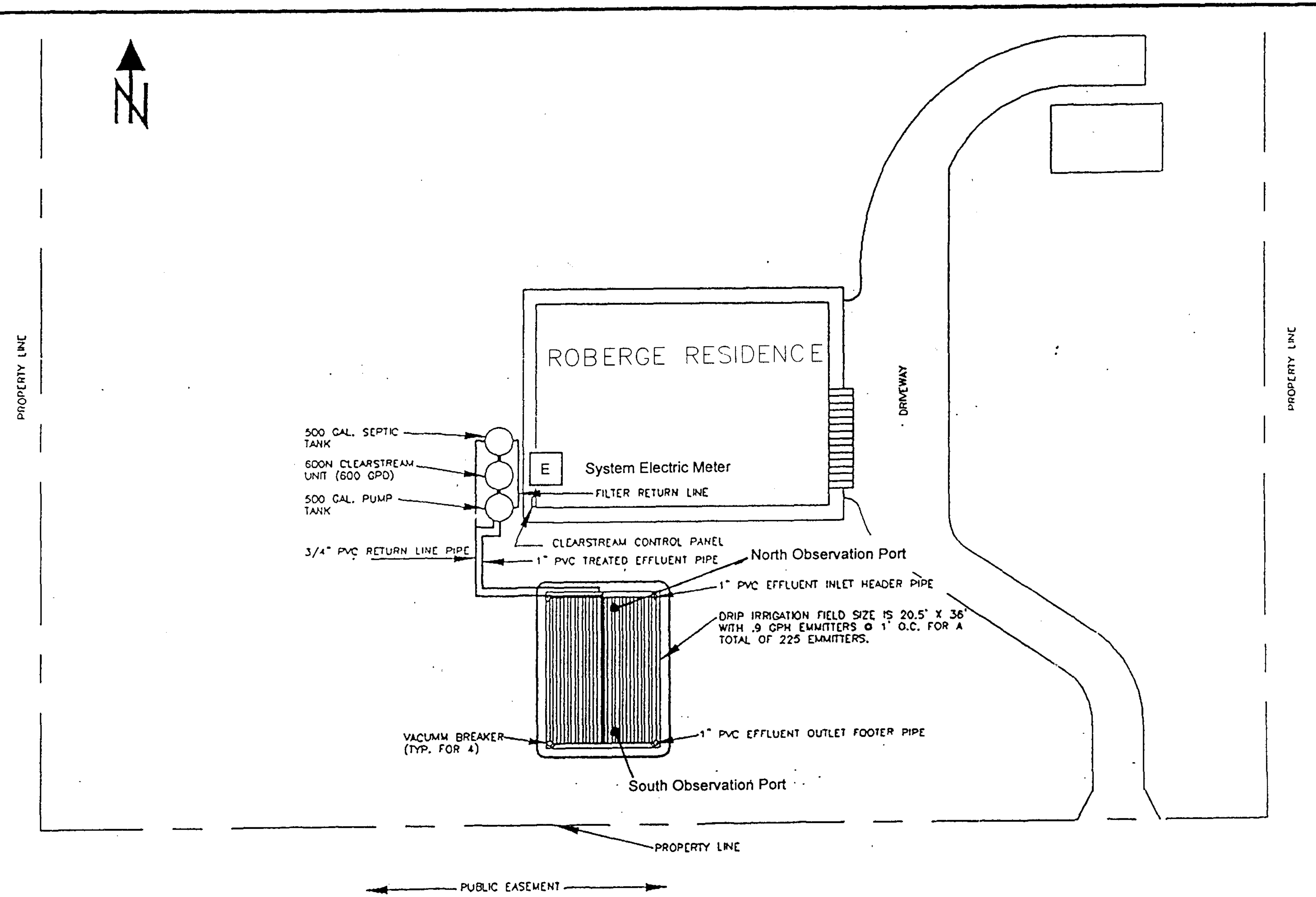

Figure 8-4. Home Site 3 SDI System Schematic

Scale: NTS

The average cost to install the SDI systems was approximately $6,100 (1996 $), which included equipment, materials, and construction costs. Permitting and abandonment of septic tanks, fees, and ATU costs were not included.

8.4 Individual Home System Monitoring

From July 25, 1996 to August 26, 1997 each home was visited 26 times to collect system data. During each site visit the following data was collected: electric use, potable water use, wastewater flow to and from the irrigation bed. Additionally, observations were made on weather conditions, and the general aesthetics of the site, including the presence of system odors, appearance of grass and condition of the irrigation bed.

During the study period, the residents of Home Site 2 were away from home August 30, 1996 to November 1, 1996. The residents of Home Sites 1 and 3 were present for the majority of the monitoring period.

8.4.1 Operational Results

The data collected for the electrical use and costs, and potable water usage and wastewater generated are summarized in Table 8-1. Logs of the collected data are presented in Appendix J. The data shows the significant variation of water use and wastewater generated from the homes. These variations cause the energy use and cost for wastewater treatment systems to also vary significantly. The energy use ranged from 0.48 kilowatt hours per day (kW-hr/day) for Home Site 2 to 1.97 kW-hr/day for Home Site 1. Home Site 3 was substantially higher than the others at 6.21 kW-hr/day due to the ATU's electrical use. The annual electricity costs were estimated using a cost of $0.10 per kW-hr. The annual costs for the SDI systems ranged from $17.50 per year (Home Site 2) to $71.91 per year (Home Site 1). The cost to operate the ATU and SDI unit at Home Site 3 was estimated at $226.67 per year. The energy use and cost for Home Sites 1 and 3 systems were consistent with the Central Testing Facility results. The estimates for Home Site 2 are slightly lower due to the presence of only two adults.

The potable water use by the homes varied from 121 gallon per day (gpd) at Home Site 2 to 392 gpd at Home Site 1. Home Site 3 used a cistern for all water use, except drinking water, and was not included in these results. The net wastewater loading to the SDI beds ranged from 117 gpd (Home Site 2) to 221 gpd (Home Site 1).

In general, the vegetation on the beds were as green or greener than the rest of the homes' yard. The beds were in good condition and remained dry. The water level beneath the beds was monitored by two 4-inch observation ports in each bed. The observation ports were installed to the bed bottom, on top of the native rock. The beds at Home Sites 1 and 2 showed no ponded effluent above the rock during the monitoring period. The bed at Home Site 3 sometimes had a slight level of ponded effluent at one end of the bed as measured from the bottom of the observation port.

Table 8-1. Summary of Individual Home Data.

Site	Estimated Daily Electric Use (kW-hrs/day)	Estimated Yearly Electric Cost ($/day)[1]	Estimated Daily Potable Water Use (gpd)	Estimated Net Wastewater Flow to Bed (gpd)
Home Site 1	1.97	$71.91	392	221
Home Site 2	0.48	$17.50	121	117
Home Site 3 [2]	6.21	$226.67	--	172

[1] Based on electric cost of $0.10 $/kW-hr.
[2] Home Site 3's electric use and cost includes a Clearstream aerobic treatment unit.

8.4.2 System Reliability and Homeowner Acceptance

The SDI systems installed at the individual home locations were generally reliable, with the exception of a few problems associated with the electrical panels. The breakers in the electrical panels at Home Sites 1 and 3 began routinely tripping after system start-up. The problem was addressed by replacing the breakers. Also, minor amounts of erosion occurred at the edges of the irrigation beds before the sod growth took hold, this was repaired, and no further problems were experienced.

For the majority of the site visits, no consistent system odors were noticed. However, odors were occasionally noted at Home Sites 2 and 3. A seal was installed on the cover of the pump chamber to correct the problem. The homeowners reported no other problems after this.

A questionnaire was sent to the homeowners to gather their input on the SDI systems. In general, all of the homeowners were satisfied with the aesthetics and performance of the systems. Additionally, the homeowners indicated they would choose a similar system if required to upgrade their OWTS.

9.0 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

9.1 Summary and Conclusions

A field evaluation of several onsite wastewater nutrient reduction systems (OWNRS) was conducted to evaluate the potential for improved treatment effectiveness by onsite wastewater treatment systems (OWTS) in the Florida Keys. In addition, the technical and economic feasibility of meeting the Florida Advanced Wastewater Treatment (AWT) standard was evaluated. Results indicated that the systems evaluated provided excellent treatment but were not capable of meeting the AWT standards for all parameters (5 mg/L $CBOD_5$, 5 mg/L TSS, 3 mg/L TN, 1 mg/L TP). All systems were able to meet the $CBOD_5$ and TSS requirements, but no system was capable of meeting all the AWT effluent standards. Based on the evaluation conducted to date, the following conclusions are presented:

1) 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;

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

3) A combination of various unit processes evaluated would achieve treatment performance by onsite wastewater systems which approached AWT 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 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.

4) 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).

5) 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;

6) The process combinations and process optimization referred to in 3) above should be evaluated at the Big Pine Key CTF to determine the level of treatment achievable by OWNRS. Other nutrient removal processes should also be evaluated to determine their performance and monetary costs.

9.2 Discussion and Recommendations

The results of this study have shown that treatment levels approaching the AWT effluent standards for CBOD, TSS, TN and TP can be achieved by OWNRS that consist of combinations of available wastewater treatment technologies. This achievement is not surprising since the technology to create drinking water from wastewater has existed for some time, as is evidenced by numerous potable reuse projects and research reported in the in the last decade (NRC, 1998; Lauer and Rodgers, 1996; California Potable Reuse Committee, 1996; Harhoff and van de Merwe, 1996; Hultquist, 1995; National Research Council, 1994; CH2M Hill, 1993; U.S. EPA, 1992). Thus, it is not a question of technology, but of need and cost. If AWT effluent from single family homes is needed at any cost, it could easily be accomplished with available technology. However, because AWT performance is not a widespread requirement for such systems, commercially available equipment is not readily available or its cost is high.

AWT standards can be met by onsite wastewater treatment systems if cost is not considered. But should AWT be our goal without regard to cost/benefit? Table 7-3 lists the cost components of the OWNRS alternatives evaluated in this study. Among the various systems tested at Big Pine Key, OWNRS combinations 3 and 5 (FAS or RBC combined with engineered media SDI) are the systems most likely to approach AWT performance. These systems are probably capable of producing an effluent of 5, 5, 5, 1 mg/L $CBOD_5$, TSS, TN, and TP, respectively. The capital cost for these OWNRS is estimated at $11,000 to $12,000 (1998 $). OWNRS combination 2 (septic tank combined with engineered media SDI), a relatively passive, natural system, would meet the same level of treatment for $CBOD_5$, TSS, and TP, but TN removal would be less at approximately 50%, with a resulting effluent concentration of 20 mg/L. The capital cost of this system is estimated to be less than $8,000. Thus, in this example, moving from a system which reduces nitrogen concentrations by 50% to one that reduces nitrogen concentrations by 87%, with all other AWT effluent parameters being equal, added approximately $4,000 or 50% to the system capital cost. Operation and maintenance costs would also be greater.

The point of this discussion is that we pay higher and higher costs for each additional increment of treatment performance. Are the environmental needs for these greater costs justified? Are both nitrogen and phosphorus removal needed for OWTS throughout the Keys? Funds will be limited for wastewater treatment in the Keys.

Therefore, is it not more fiscally responsible to remove as much nitrogen and phosphorus as possible with the limited funds available, thus maximizing the benefit achieved? These are policy questions which must be answered before we move ahead with a stringent standard for one of many sources of nutrients to nearshore waters in the Keys.

If it is determined that AWT standards are necessary for onsite systems, what can be done to make these systems more affordable to residents? A county-wide utility district that includes all residents of both sewered and unsewered developments, could amortize costs for individuals and also be eligible for public financing (SRF loans for example). Such a utility could include individual OWNRS, clusters of homes on small nutrient reducing treatment systems, and sewer systems with a central treatment plant for more densely developed areas that could justify the cost. Spreading the cost of nutrient removal over all residents via a utility could potentially accomplish greater nutrient reductions than requiring AWT for onsite systems alone.

A wastewater master plan that analyzes *all* wastewater treatment needs in the Keys and allocates costs appropriately to achieve maximum benefit is needed. A plan for unincorporated Monroe County is currently underway; the "Monroe County Sanitary Wastewater Master Plan". The results of this plan may aid in the decision as to which treatment standard should be required for onsite wastewater systems, as well as other wastewater systems established in the Keys.

Based on the results of the OWNRS Demonstration Project and our experience with onsite wastewater management, the following recommendations are made for OWNRS in the Florida Keys.

- Consideration should be given to delaying implementation/enforcement of the AWT requirement for onsite wastewater systems until completion of the Monroe County Sanitary Wastewater Master Plan (SWMP). Once adopted, this plan will provide a wastewater management plan for the Keys that will define where sewer systems and treatment plants should be located, where clustered wastewater systems are feasible, and where continued use of onsite wastewater treatment is appropriate. Resources spent now for OWNRS may only be lost as the OWNRS are replaced by sewers or clustered systems in the near future. These funds could achieve greater benefit under a well planned wastewater management program.

- Consideration should be given to a nutrient removal standard other than AWT for OWNRS in the Keys. Under the SWMP, densely developed areas of OWTS will probably be more economically served by sewers or clustered wastewater systems, and OWNRS will be used in less densely developed areas. AWT may not be needed in areas of low density. Also, since OWTS typically do not include infiltration/inflow and have much higher raw wastewater nutrient concentrations, an AWT requirement for OWTS implies greater removal of nutrients than it does for a treatment plant, thus justifying a higher concentration standard. A passive, natural system such as an engineered media SDI system could provide AWT levels of treatment for BOD, TSS, and TP and approximately 50% reduction in nitrogen. Such a system is lower in cost, simpler to operate, and more consistent in performance than other systems tested, and would probably *not* require performance monitoring of effluent quality.

- The development of a county-wide utility to handle all wastewater management, including onsite wastewater systems, should be promoted in Monroe County. Such an approach would allow more cost-effective treatment, including clustered systems and multiple home use of single OWNRS. A utility would also allow amortization of costs for individual homeowners as well as eligibility for public financing programs.

The waters of the Florida Keys are a unique natural system that deserve protection. However, since cost is a key factor in reducing anthropogenic nutrient loads to nearshore waters, we must allocate available funds to achieve the greatest overall reductions in nutrient loading. We cannot afford to remove all nutrients from all sources. A plan must be developed that considers all nutrient sources, available funding to address the problem, and how the available resources can be allocated to result in the greatest possible nutrient reductions to nearshore waters. The use of OWNRS to reduce the nutrient load from onsite wastewater systems can play a significant role in such a plan. This report provides a preliminary basis for evaluating this role.

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