Environmental Impact of Wastewater Disposal in the Florida Keys, Monroe County

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Abstract

Studies indicate nutrient levels in the coastal waters surrounding the Florida Keys are increasing and sewage disposal is suspected to be a source of nitrogen that is adversely affecting the normally oligotrophic marine waters. Typical methods of wastewater disposal include large municipal wastewater treatment plants, smaller "package" wastewater treatment plants, and onsite sewage treatment and disposal systems, also known as septic systems. Treated wastewater effluent from these systems is disposed via injection wells or drainfields into the geological substrate of the Keys. Tracer studies indicate nitrogen-rich effluent is rapidly flowing from the subsurface into the coastal waters, resulting in excessive biomass of macroalgae that stunts juvenile coral growth, overgrows seagrasses, and causes areas of anoxia and hypoxia. Although current onsite sewage treatment methods are somewhat effective at reducing pathogens in wastewater, nutrient levels are not significantly decreased. The Florida Department of Health is conducting research to develop onsite wastewater systems that are low cost, easily maintained, and significantly reduce nitrogen levels.

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According to the Florida Department of Health, there are more than 2.6 million on-site sewage treatment and disposal systems (septic systems) across the state. Rural areas have the highest numbers of septic systems because municipal infrastructure is not in place to convey sewage from homes and business to central sewer treatment plants. The United States Environmental Protection Agency says "adequately managed decentralized wastewater systems are a cost-effective and long-term option for meeting public health and water quality goals, particularly in less densely populated areas" (USEPA, 1997). Septic systems are utilized successfully in most improved rural areas within the Florida mainland. However, use of septic systems in coastal areas is difficult due to unsuitable soils and the inability to achieve safe setbacks to water source wells and surface water bodies because of high population density. Scarcity of suitable soils and the sprawling nature of the Florida Keys makes adequate sewage disposal problematic. Drainfields and sewage injection wells were permitted for years as a convenient and inexpensive way to dispose of septic tank and sewer plant effluent. Research throughout the last 20 years indicates this method of sewage disposal is having a detrimental effect on the delicate marine ecosystem surround the Keys.

Florida Keys Geology and Ecosystems

The Florida Keys are a low elevation archipelago stretching from near Miami, curving south and southwest, and terminating at the Dry Tortugas, although the Oversees Highway ends at Key West, the southernmost city in the Florida Keys and the continental United States. The geology of the Keys is composed of the Key Largo Limestone and Miami Limestone formations (Corbett, 2000). The Key Largo Limestone is porous and consists of ancient stony corals with intra- and imbedded calcarenites and thin layers of quarts. Miami Limestone is composed of well-sorted ooids mixed with skeletal material and is much less permeable than the Key Largo Limestone. The impermeable nature of the Miami Limestone supports small subsurface freshwater lenses in some locations (Corbett, 2000). The Miami Limestone is found on Big Pine Key and ranges south-westward to Key West. The Key Largo Limestone ranges from north of Big Pine Key to Key Largo.

Groundwater flow in the Keys is unique as compared to other unconfined aquifers in Florida because the primary forcing mechanism is tidal, with the exception of the shallow freshwater lenses supported by the relatively impervious nature of the Miami Limestone.

Studies have shown that sea level in Florida Bay is on average higher than the Atlantic side of the Keys, suggesting total groundwater flow is from Florida Bay, through the Keys, and towards the Atlantic with daily oscillation, or tidal pumping, being the result of tidal forces (Corbett, 2000).

The marine waters surrounding the Keys are tropical and normally oligotrophic, supporting extensive patch and bank reefs, seagrass beds, and mangroves (Lapoint, 1990). The only significant coral reef system in the continental U.S. exists around the Keys (Paul, 1997). Scientific evidence supports significant impact of sewage pollution on water quality and health of seagrasses and corals (Lapoint, 2004). Nutrient levels in sewage pollution are considerable relative to the low nutrient environment of the marine waters surrounding the islands. Dissolved inorganic nitrogen (DIN) composed of ammonium (NH_4^+), nitrate ($N0_3^-$), and nitrite ($N0_2^-$) is causing an excessive biomass of macroalgae that overgrow seagrasses and adult corals, obstruct development of juvenile coral, and develop areas of anoxia and hypoxia, depleting fish populations and other biological diversity (Lapointe, 2004). Furthermore, sewage contamination in the marine ecosystem surrounding the Keys is a public health hazard due to known microbiological components such as *Escherichia coli* and *Enterococcus*.

Florida Keys Sewage Treatment and Disposal

Florida Administrative Code Rule 64E-6 regulates onsite sewage treatment and disposal systems in Florida for sewage flows of less than 10,000 gallons per day. This rule is divided into two main sections; the first set of rules is for systems that are constructed on the mainland, the second set for those placed in service in the Keys. The significant difference between the Florida mainland and the Keys is the presence or absence of soils suitable for filtration of sewage effluent from septic tanks. Sandy soils exist in most regions of the Peninsula to several meters in depth but only a few inches at best in the Keys. Until the late 20^{th} Century, it was reasonable to view the very geological structure of the Keys as a method for disposing sewage since no usable freshwater aquifer exists there.

Discharge of sewage into cesspits, shallow holes, and directly into the adjacent coastal water were common methods of sewage disposal during the years of early development of the Florida Keys. Ecological impact was minimal due to the sparse population common during the first half of the 20^{th} century. However, the Keys gradually became a popular vacation destination and a desirable place to live because of climate and proximity to pristine ocean waters. Since land area is limited, early subdivisions were high density with 50 foot by

50 foot lot sizes not uncommon (Kruczynski and McManus, 2002). Direct release of untreated sewage resulted in nutrient enrichment and pollution of ground water and nearby surface waters with human fecal pathogens. The State Board of Health gradually adopted rules and enforced the use of septic systems during the mid 1960's to protect public health. Components of these septic systems included a septic tank with effluent disposal achieved using a drainfield or injection well. The porous nature of the Keys substrate limestone results in high nutrient effluent seeping directly into groundwater and adjacent surface waters. Starting in 1992, the Florida Department of Health required that drainfields be underlined by a minimum 12 inches of clean fill sand (Kruczynski and McManus, 2002). Although underlying drainfields with clean fill sand provides filtration of pathogens through cation exchange entrapment, little or no removal of nutrients such as nitrogen or phosphorus is afforded (Kruczynski and McManus, 2002). Furthermore, early installed septic tanks were punctured, allowing infiltration of groundwater to prevent groundwater induced flotation of the tanks. This practice short-circuits the system and allows raw sewage to directly contact groundwater (Kruczynski and McManus, 2002).

According to a 2009 Florida Department of Health study completed by EarthSTEPS and GlobalMind, Monroe County identified more than 23,000 land parcels with on-site sewage treatment and disposal systems, including cesspits (FDOH, 2009c). Other studies estimate the existence of 25,000 permitted septic systems and more than 5,000 illegal cesspits located throughout the Keys, including the sparsely populated mainland section of the county (Lapointe, 2004). Small sewage treatment plants, known as "package plants" treating less than 100,000 gallons of sewage per day are used throughout the Keys and typically serve multifamily dwellings, motels, resorts, and small municipalities (Paul, 1997). The Florida Department of Environmental Protection is responsible for permitting and regulating these systems. Currently there are 168 permitted domestic package plants in Monroe County (FDEP, 2011). The majority of sewage generated in the Keys is treated by 18 large treatment plants with permitted capacities greater than 100,000 gallons per day and serve large residential areas and larger municipalities such as Key Largo, Marathon, and Key West (Kruczynski and McManus, 2002). Table 1 shows the total number of permitted package plants, large treatment plants, and estimated septic systems in Monroe County.

Wastewater treatment plants permitted by Florida Department of Environmental Protection (FDEP) are required to meet minimal secondary treatment and disinfection criteria. These requirements include regular supervision and monitoring of the facilities by a licensed wastewater treatment plant operator and oversight by FDEP inspectors to ensure rule and statute compliance. Secondary treatment and disinfection criteria includes removal of up to 90% of total suspended solids (TSS) and organic carbon wastes that produce oxygen demand (CBOD) in the wastewater. The secondary treatment process also removes organic nitrogen and phosphorus associated with the suspended solids but is not effective in removing dissolved nutrients such as nitrates and phosphates. Chlorination of the treatment plant effluent disinfects by neutralizing pathogens. Sludge is periodically extracted from the plants' settling tanks and disposed of in FDEP approved facilities on the mainland (Kruczynski and McManus, 2002).

Table 1
Monroe County Sewage Treatment Systems
Type of facilities, total number of facilities, estimated sewage flow, and percentage of sewage treated.

Facilities	Number	Estimated maximum daily sewage flow	Percent of sewage treated
Large treatment plants (>100,000 gpd)	18	15 million gallons	60%
Small treatment plants (<100,000 gpd)	167	3 million gallons	12%
On-site treatment systems (septic systems)	23,000*	6.9 million gallons**	28%

* Florida Department of Health statistics, including suspected 5,000 illegal unpermitted systems and cesspools.
**Assuming average sewage treatment of 300 gallons per day per system.

The primary method for disposing of wastewater treatment plant effluent is Class V, Group 3 injection wells. These wells are regulated by Florida Administrative Code Rule 62-528 and include all wastewater injection wells that are part of treatment plant effluent and septic systems serving multiple family dwellings, communities, and business establishments. Class V Group 3 wells must be drilled to a depth of 90 feet and grouted with cement to a depth of 60 feet. Users of these wells must provide reasonable assurance that operation of the wells does not "cause or contribute to a violation of surface water standards" (Kruczynski and McManus, 2002). Class V Group 3 wells serving individual or single family (less than 20 people per day) are regulated by Department of Health's Florida Administrative Code Rule 64E-6. Over 600 Class V Group 3 wells exist throughout the Keys (USGS, 1994).

Water Quality Degradation Indicators and Studies

Water quality in Florida Bay began showing signs of significant degradation in the late 1980s. Clear water began to turn green and turbid with seagrass die-offs and algae blooms occurring with greater frequency (Dillon et al., 2000). Causes of these ecological changes were hypothesized to be elevated salinity and increased nutrient loading due to the urbanization of the south Florida mainland and the Keys. Still others suspected natural variability within the ecosystem (Dillon et al., 2000). Coral die-offs, coupled with colonization of benthic algae on dead and dying coral indicated increased nutrification of the coastal waters around the Keys.

Sewage disposal methods in the Keys were suspected to be the source of nutrification of the coastal water surrounding the islands (Paul et al., 1995). The presence of bacteria commonly found in sewage, such as fecal coliform and fecal streptococci, do not necessarily indict sewage disposal as the source as these microorganisms has been found to occur naturally in surface water bodies and groundwater. However, a direct connection between septic systems and marine water was shown in a 1995 study conducted in the Upper Keys that seeded septic tanks and injection wells with different bacteriophages and following their fate as a function of time (Paul et al., 1995). Marine bacterium HSIC was isolated from a sample obtained from Ke'ehi Lagoon in Honolulu, Hawaii. Bacteriophage ΦHSIC-1 was isolated and grown to a high titer of 10^{12} plaque forming units per milliliter (PFU/ml) and 200 ml of ΦHSIC-1 lysate was flushed down a toilet once an hour for five hours at National Undersea Research Center located on the Port Largo Canal. A standard septic system with a tank and drainfield received influent from the toilet. Also flushed at the same time were fluorescent Flouresbrite spheres ranging from 0.7 to 1 µm in diameter. The fluorescent spheres were flushed at a volume of 10 ml per flush. An injection well was seeded with *Salmonella* bacteriophage PRD1, which was obtained from the University of Arizona, Tucson. This phage was diluted in 10 liters of well water and a Shaklee diaphragm pump was used to introduce the solution into the well (Paul et al., 1995).

Bacteriophage ΦHSIC-1 introduced into the septic system was first detected in a shallow monitoring well 20 meters away from the septic system within 7 hours of the beginning of the seeding period (Paul et al., 1995). The bacteriophage was then detected at a canal test point located 167 meters from the septic system 11 hours after seeding. The phage was subsequently detected at three other canal test points after 15, 23, and 31 hours. A monitoring well located 50 m off-shore and more than 600 m from the septic system yielded the phage 55 hours after seeding (Paul et al., 1995). The fluorescent spheres were also detected in the same shallow monitoring well 7 hours after seeding. A green phosphorescing cloud was observed in the water of a canal near the septic system approximately 33 hours after seeding (Paul et al., 1995). The injection well seed study yielded one positive sample of a possible indigenous *Salmonella* phage before the well was actually seeded. Nevertheless, the seeded phage, PRD1, was detected in a nearby canal approximately 11.2 hours after seeding. Thereafter, the phage was detected in the same shallow monitoring well as the septic system phage was detected. The final detection of PRD1 occurred 35 hours after seeding at a canal adjacent to the injection well (Paul et al., 1995).

A second study conducted in the Middle Keys in 1996 yielded similar results. A recently installed Class 5 wastewater injection well drilled to a depth of 27.4 meters (90 feet) was chosen. As in the 1995 study, bacteriophages ΦHSIC-1 and PRD1 were used, but coliphage MS2 was also included in the 1996 study (Paul et al., 1996). The three phages were divided into five equal aliquots, each added separately to the injection well hourly for five hours (Paul et al., 1997). Wastewater was simultaneously flowing into the well. All three phages were detected in three pairs of monitoring wells. These wells were drilled to depths of 4.6 m and 13.7 m with one shallow and one deep monitoring well paired together. The well pairs were 4.5, 5.4, and 6.1 meters from the injection well. Bacteriophage ΦHSIC-1 was detected in the surface water at a test point in Florida Bay located 167 meters away from the injection well (Paul et al., 1997).

Tracer experiments were conducted by Dillon et al. in 1996 and 1997 using a Class 5 injection well located at the Keys Marine Laboratory. Slug injections introduced into the well were composed of sulfur hexafluoride gas bubbled into 200 liters of tap water. Iodine-131 was also used by dissolving ^{131}I into a 50-L injection slug. Solutions were siphoned into the injection well followed by a chaser of approximately 1000 L of wastewater. During the first experiment in October 1996, Sulfur hexafluoride was detected at 7 monitoring well clusters, each grouping having wells drilled to 4.6, 9.1, 13.7, and 18.3 m. Two hours after slug injection, SF^6 was measured in an 18.3-m deep monitoring well located 5 m from the injection well and continued to be detected in monitoring wells after 69 d (Dillon et al., 2000). The February 1997 experiment used sulfur hexafluoride and iodine-131. The ^{131}I

mimicked the SF^6 results, which was detected in monitoring wells and in surface water samples collected from Florida Bay and the Atlantic (Dillon et al., 2000).

A study conducted from 2003 to 2005 by Futch et al. indicates that fecal coliform and Enterococci are reaching offshore reefs, albeit at low levels. A transect ranging from near-shore to offshore was evaluated for traditional microbiological indicators of sewage contamination to detect fecal bacteria and human enteric virus (Futch et al., 2010). In this study, 25 samples were collected from each coral secreted surface mucopolysaccharide layer (SML), surface water, and ground water (Futch et al., 2010). Fecal coliform counts ranged from non-detectable to 105 colony forming units per 100 milliliters (105 cfu ml^{-1}) in SML, non-detectable to 3.5 cfu 100 ml^{-1} in the groundwater (Futch et al., 2010). Enterococci ranged from non-detectable to 700 cfu 100 ml^{-1} in SML. Surface water enterococci results ranged from non-detectable to 10 cfu 100 ml^{-1} and from non-detectable to 41 cfu 100 ml^{-1} in groundwater (Futch et al., 2010). Florida Administrative Code Rule 32.302.530 classifies recreational marine water quality as “good” if fecal coliform bacteria quantity is less than 199 fecal coliform per 100 ml^{-1} and enterococci is less than 35 cfu 100 ml^{-1} for a single sample. Following this criteria, only the SML and groundwater sample results exceeded health advisory levels.

Nutrient couplings between onsite wastewater systems and adjacent marine waters were studied by LaPointe et al. (1990) between December 1986 and September 1987. Monitoring wells were installed on seven residential lots that were inhabited for at least 3 yr and up to 20 yr (LaPointe et al., 1990). The wells were installed in pairs, one near the septic system and the other midway between the septic systems and adjacent canals at each residential lot. Water samples were collected monthly from every well and analyzed for salinity, temperature, and dissolved inorganic nutrients (Lapointe et al., 1990). Two statistical comparisons were made in this study. First, monthly groundwater and surface water nutrient concentration data from the winter and summer were pooled separately to determine any significant difference between the wet and dry season (LaPointe et al., 1990). Second, the pooled seasonal nutrient data from both monitor wells at the residential sites was compared to the control data (see Table 2). Nutrient enrichment was significant (up to 5000 fold) with the highest concentrations of ammonium, nitrate plus nitrate, and soluble reactive phosphate occurring in monitoring wells adjacent to septic system drainfields as compared to the control groundwaters (Lapointe et al., 1990). Lower concentration of these nutrients, although still enriched, occurred in groundwaters extracted from wells installed midway between septic system drainfields and surface waters. Lowest concentrations of nutrients occurred in control groundwaters extracted from wells installed within the Key Deer National Wildlife Refuge (Lapointe et al., 1990). Mean concentrations of nutrients in groundwaters decreased from winter to summer, contrasting with increases in measured nutrients in surface water from winter to summer.

Table 2
Mean Values for Nutrient Concentrations (micro molar, μM)

Location	Mean nitrate plus nitrite	Mean ammonium	Mean soluble reactive phosphate
Winter			
Adjacent wells[1]	817	784	17
Midway wells[1]	118	256	2.54
Wells combined[2]	467	520	9.77
Control groundwater[3]	0.76	1.91	0.11
Canal[4]	1.61	0.88	0.15
Summer			
Adjacent wells[1]	220	502	6.37
Midway wells[1]	30.7	188	1.62
Wells combined[2]	125	346	4.0
Control groundwater[3]	0.20	1.40	0.14
Canal[4]	3.22	1.69	0.43

Notes

1. **Adjacent wells** – water extracted from wells installed adjacent to septic systems, pooled data.
   Midway wells – water extracted from wells installed midway between septic systems and canals, pooled data.
2. **Wells combined** – water extracted from adjacent wells and midway wells, then pooled.
3. **Control groundwater** – water extracted from monitoring well installed at Key Deer National Wildlife Refuge (KDNWR)
4. **Canal** – Surface water collected from canal systems adjacent to septic system sites.

Source: Adapted from Lapointe et al., 1990

The elevated nutrient concentrations, summarized in Table 2, indicate that wastewater effluent from septic systems is a significant source of enrichment to groundwater and surface waters in the Keys (Lapointe et al., 1990). The predominant nitrogenous species in the groundwater was ammonium, likely caused by suboxic and anoxic conditions due to limited vadose zone underlying septic systems, preventing maximum nitrification (Lapointe et al., 1990).

The Future of Wastewater Disposal in the Florida Keys

The Florida Department of Health (FDOH) is researching sewage nutrient reduction methods for onsite wastewater treatment and disposal systems (septic systems). In 2008, the State Legislature appropriated 1 million dollars for a 3-5 year research project to develop passive nitrogen reduction methods for septic systems (FDOH, 2011a). Passive nitrogen removal has been defined by FDOH as "a type of onsite sewage treatment and disposal system that excludes the use of aerator pumps and includes no more than one effluent dosing pump with mechanical and moving parts and uses a reactive media to assist in nitrogen removal." This definition of passive requires septic systems capable of reducing nitrogen to be "simple in design, easy to use, and require little attention by the owner" (FDOH, 2009a). The goal of this definition of passive is to develop septic systems capable of reducing Total Nitrogen (TN) levels in wastewater to a minimum of 10 milligrams per liter, which is the maximum contaminant level allowed by the United States Environmental Protection Agency for nitrates and nitrites in drinking water. Nitrogen loading is not only a problem in the coastal waters of the Florida Keys but also in Florida's freshwater springs where excessive algae growth occurs with nitrogen levels as small as one milligram per liter.

Overview of Nitrogen Reduction Technologies and Processes

Three major technologies available for nitrogen reduction within onsite wastewater systems include natural systems, source separation, and biological nitrification and denitrification (FDOH, 2009a). Natural onsite wastewater systems traditionally utilized throughout Florida and in the Florida Keys are passive, low maintenance, and rely on the assimilative capacity of the receiving environment to absorb and treat effluent and associated constituents. These systems are composed of a treatment receptacle (septic tank) and drainfield. Effluent treatment occurs in all components of a standard OSTDS with natural treatment occurring in the soil underlying the drainfield absorption surface. While these conventional systems are simple and operate years without failure, they do not adequately reduce nitrogen from wastewater in areas with environmental nitrogen sensitivity (FDOH, 2009a). At best, conventional systems will reduce TN in the wastewater by 35% (Ritter and Eastburn, 1988). Considering typical domestic sewage influent contains 60 mg/l TN, septic system effluent at best will contain 39 mg/l TN, almost 4 times higher than EPA standards for drinking water.

Source separation involves separating the wastewater steam into its components with the goal of maximizing best treatment and reuse methods. Total sewage flow is separated into separate streams of greywater and black water, with greywater being further separated into bath and shower, laundry, and lavatory. Black water is separated into kitchen and toilet with toilet being further separated into urine and fecal (FDOH, 2009a). Kitchen wastewater is considered to be black water because biological oxygen demand (BOD), total suspended (TSS) and pathogen associated with food preparation are significant (FDOH, 2009a). Urine, while accounting for about 1% of the total daily volume of wastewater, has the highest content of TN, almost 5000 mg/l (FDOH, 2009a). A number of processes are available to reduce nitrogen in urine with precipitation of struvite (magnesium ammonium phosphate) being the simplest (FDOH 2009a). Greywater accounts for approximately 50% of the total domestic wastewater stream but contains a small percentage of nutrients. The separation of greywater allows for reuse for irrigation, toilet flushing, or disposed of using an standard onsite septic system. Greywater separation reduces wastewater volume and black water can be treated by membrane filtration to reduce nutrient levels (van Voorthuizen et al., 2008). Although source separation is effective at reducing nutrient loading in the environment, it is not a viable option because significant reconfiguration of plumbing in existing structures is required. Furthermore, the purchase and installation of special fixtures such as urine separating toilets and/or urinals is necessary. New building construction could be designed to accommodate this technology but retrofitting existing structures will be cost intensive (FDOH, 2009a).

Biological nitrification and denitrification reduces TN in a two phase process occurring in order of nitrification followed by denitrification (Smith et al., 2008). Nitrification occurs in two steps. The first step is accomplished by bacteria of genus Nitrosomonas that require oxygen to convert ammonia to nitrite and is described by the equation (1) below (USEPA, 2007).

$$NH_3 + O^2 \xrightarrow{\text{Nitrosomonas}} NO_2^- + 3H^+ + 2e^- \quad (1)$$

The second step of nitrification converts nitrite to nitrate and is accomplished by nitrite oxidizing bacteria called Nitrobacter and is described by equation (2) below (USEPA, 2007).

$$NH_3 + O^2 \xrightarrow{\text{Nitrobacter}} NO_2^- + 3H^+ + 2e^- \qquad (2)$$

Denitrification involves the use of facultative anaerobic bacteria that metabolize nitrate by reducing nitrate to gaseous nitrogen that is off-gassed into the atmosphere, thus removing TN from wastewater (USEPA, 2007). Denitrification must occur in the absence of oxygen for the bacteria to utilize the nitrates for metabolism. The sequence of this process is generally described by equations (3) and (4) below (Lin et al., 2007).

$$2\,NO_3^- + 4\,e^- + 4H^+ \rightarrow 2\,NO_2^- + 2\,H_2 0 \qquad (3)$$

$$2\,NO_2^- + \ 6\,e^- + 8H^+ \rightarrow N_2 + 4\,H_2 0 \qquad (4)$$

Biological nitrification and denitrification processes are divided into four subcategories: 1) mixed biomass with alternating aerobic and anoxic environments, 2) mixed biomass recycling systems, 3) two stage external electron donor denitrification, and 4) aerobic ammonium oxidation (FDOH, 2009a). Total nitrogen removal within on-site wastewater systems requires nitrification and denitrification (described previously) in processes 1 through 3. These processes are summarized below.

1) Mixed biomass with alternating aerobic and anoxic environments simultaneously combine nitrification and denitrification activities into one bioreactor by alternating periods of aerobic and anoxic conditions (FDOH, 2009a). Commonly used configurations in this method include recirculating sand filters, recirculating peat filters, and recirculating textile filters (Smith et al., 2008). These types of systems reduce wastewater TN by approximately 50 percent, insufficient for oligotrophic environments (Smith et al., 2008).

2) Mixed biomass recycling systems use separate anoxic and aerobic bioreactors with a portion of effluent from the aerobic bioreactor being back-circulated to the anoxic bioreactor where reduction of nitrate to nitrogen gas is achieved using carbonaceous organics from the incoming untreated wastewater as the electron donor (FDOH, 2009a). Total nitrogen removal is limited from 40 to 75 percent.

3) Two stage external electron donor denitrification process follows the nitrification /denitrification process by using an aerobic bioreactor followed by an anoxic bioreactor. An external electron donor must be introduced to the anoxic bioreactor to achieve denitrification (FDOH, 2009a). Two stage systems are capable of reducing TN by more than 95 percent (Smith et al., 2008).

4) Aerobic ammonium oxidation (process 4), also known as anammox, is an anaerobic ammonium oxidation pathway where nitrite and ammonium convert to N_2, nitrogen

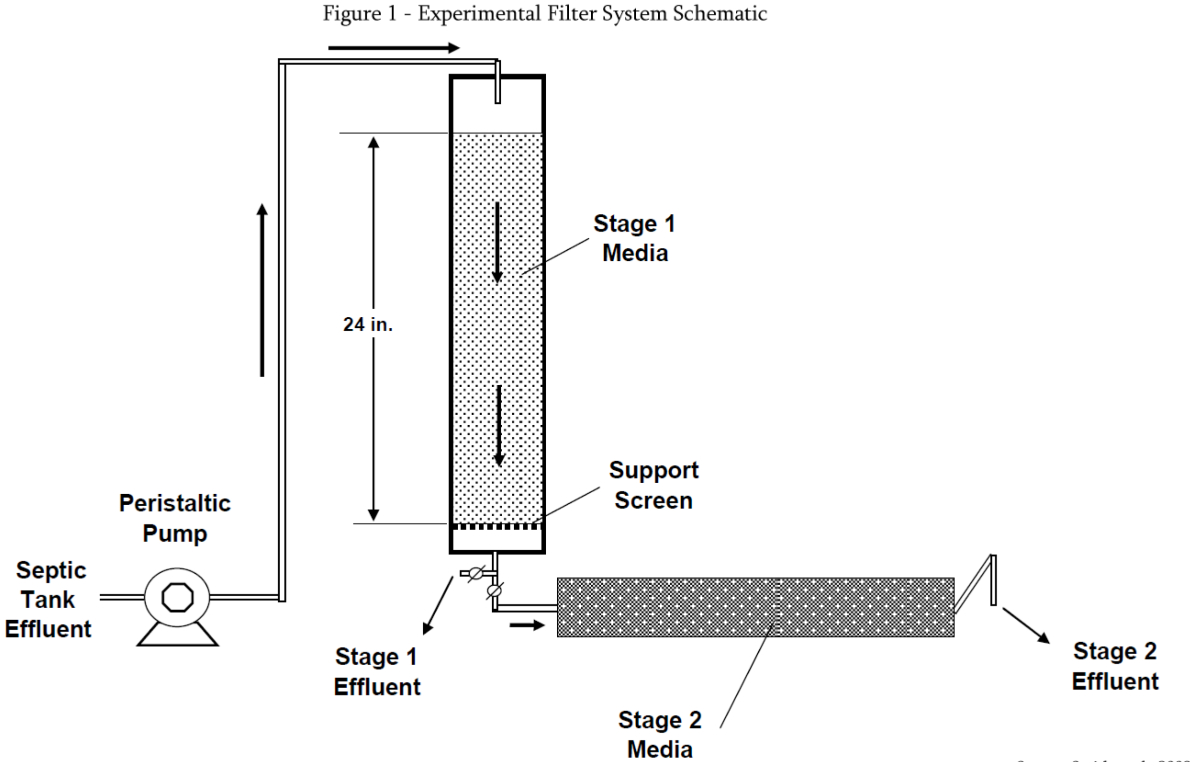
gas (FDOH, 2009a). This conversion is accomplished by bacteria that are a member of the phylum planctomycetes. Anammox is newly recognized and the process has yet to be explored for nitrogen reduction in onsite sewage treatment systems and TN removal capabilities are unknown (FDOH 2009a).

The two stage external electron donor nitrification has the most promise for being used in passive nitrogen reduction for onsite wastewater treatment and disposal systems for two reasons. First, research shows this method is most effective at removing TN from wastewater (Smith et al., 2008). Second, such a system can be designed and placed in series after newly installed or existing septic tanks, potentially allowing the entire system to achieve total nitrogen reduction with gravity flow, negating the need for a dosing or lift pump. However, systems installed in areas with a high seasonal high water table will need a lift pump to achieve the required system elevation allowing the required separation from the water table.

PNRS I – Experimental Study

Passive Nitrogen Reduction Study (PNRS I) of the two stage external electron donor method was conducted beginning in January, 2008 at Flatwoods Park. The park is a day-use facility in Hillsborough County. The onsite septic system accepts effluent from a restroom facility and the park manager's single family residence (Smith et al., 2008).
Three two-stage filtration systems were constructed using 3 inch (internal diameter) PVC

Figure 1 - Experimental Filter System Schematic



Source: Smith et al., 2008

pipe for the Stage-1 aerobic filter and 1.5 inch (internal diameter) PVC pipe for the anaerobic Stage-2 filters (Figure 1). Each Stage-1 filter was equally dosed with septic tank effluent using a three head peristaltic pump manifolded to a single tube extracting from the septic tank. Effluent from each Stage-1 filter flows into each Stage-2 filter. Stage-1 filter media was chosen for substantial external porosity and included (separately) clinoptilolite, expanded clay, and tire crumb. To provide maximum surface area for microbial attachment, the stage-1 filter media was sorted and placed into the PVC filter housing so the smallest particles were in the center and larger particles at the top and bottom. Stage-2 filter media was composed of elemental sulfur (electron donor), oyster shell (pH control) and expanded shale at different ratios. Table 3 contains specifics regarding each filter (Smith et al., 2008).

Operation of the experimental filters began on January 2, 2008. Three weeks was allotted to allow for microbiological colonization in the filters. Throughout the testing period, all filters were dosed at a rate of 3 gallons per day per square foot of surface area. Sampling began on day 22 and continued on five different occasions through day 62. Nitrogen removal averages for the three filters are shown in Table 4. Filters A and B show significant reduction of TN with efficiency in excess of 97 percent. Filter C only provided 33 percent TN removal (Smith et al., 2008).

PNRS II – Experimental Study

Passive Nitrogen Reduction Study II (PNRS II) is underway at the University of Florida Gulf Coast Research and Education Center (GCREC) in Hillsborough County. The facility is designed to extend and expand testing of the two stage method simultaneously with recirculating biofilter and unsaturated in-situ simulator biofilter systems while using a similar sewage source (FDOH, 2010). Descriptions and schematic of these systems follow.

- Group I – Single Pass two-stage filtration consisting of unsaturated nitrification biofilters followed by saturated anoxic denitrification biofilters. Septic tank effluent is first treated by unsaturated biofilter followed by saturated biofilter (FDOH, 2010).

Table 3 – Two Stage Filtration Method

Stage	Filter	Column diameter (inches)	Media depth (inches)	Media placement	Media	Depth. (in)	particle diameter (mm)	
Stage 1 Unsaturated aerobic	1A	3.0	24.0	Stratified	Clinoptilolite	8	2.38-4.76	top
						8	1.19-2.38	↓
						6	0.5-1.19	↓
						1	1.19-2.38	↓
						1	2.38-4.76	bottom
	1B				Expanded Clay	8	3-5	top
						8	1.0-2.0	↓
						6	0.5-1.0	↓
						1	1.0-2.0	↓
						1	3-5	bottom
	1C				Tire Crumb	8	3-5	top
						8	1.0-2.0	↓
						6	0.5-1.0	↓
						1	1.0-2.1	↓
						1	3-5	bottom
Stage 2 Saturated anoxic	2A	1.5	24.0	Nonstratified (1-3 mm)	75% elemental sulfur 25% oyster shell			
	2B				60% elemental sulfur 20% oyster shell 20% expanded clay			
	2C				45% elemental sulfur 15% oyster shell 40% expanded clay			

Source: Smith et al., 2008

Table 4 – Nitrogen Species in Filter and Effluents

Average of 5 sampling events (n=4). All values in mg/L

Sample Point	Total Nitrogen	Total Kjeldahl Nitrogen	Organic N	NH_3-N	NO_x-N	Total Inorganic Nitrogen
Influent (septic tank)	77.4	73.2	20.7	52.5	4.2	56.8
Stage 1 Effluent						
1A Clinoptilolite	35.2	8.9	2.2	0.1*	26.3	33.0
1B Expanded Clay	56.2	1.0	0.9	0.1	55.2	55.3
1C Tire Crumb	65.4	29.0	2.4	26.6	36.4	63.0
Stage 2 Effluent						
2A (75% Sulfur)	2.2	2.2	2.1	0.11	0.03	0.14
2B (60% Sulfur)	2.1	2.0	1.4	0.61	0.02	0.63
2C (45% Sulfur)	43.9	36.6	1.8	34.8	7.3	42.1

*n=4

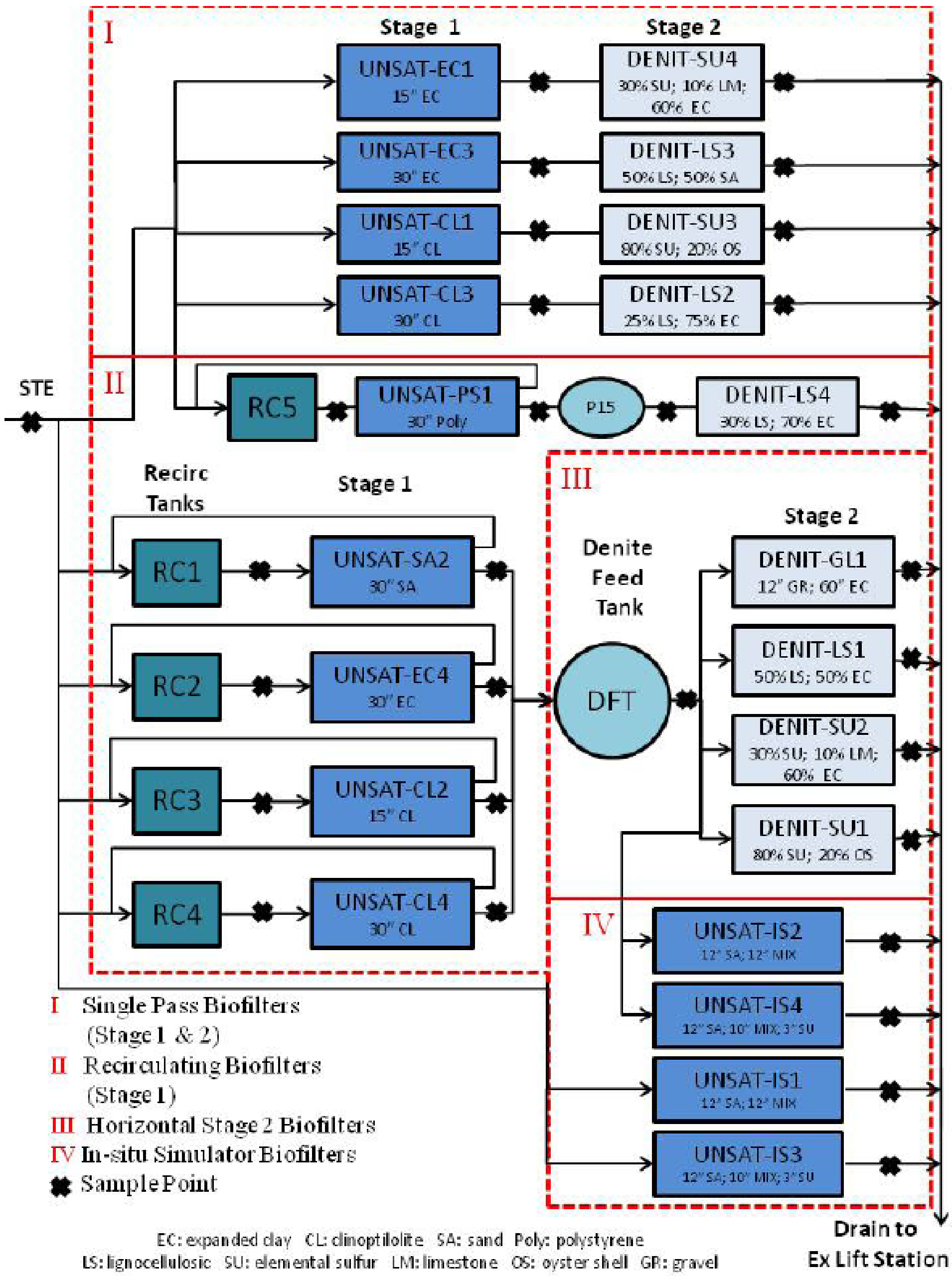
Source: Smith et al., 2008

- Group II – Utilize unsaturated nitrification biofilters followed by recirculation pump tanks that return a portion of the effluent to the unsaturated biofilter for further treatment. The balance of the effluent is then pooled and treated by saturated denitrification biofilters in Process III. One Group II biofilter effluent is not pooled with the rest but is treated by an individual denitrifying biofilter (FDOH, 2010).

- Group III – Saturated denitrifying biofilters that receive effluent from Process II recirculating biofilters (FDOH, 2010).

- Group IV – Unsaturated in-situ biofilters designed to test the efficiency of filter media as part of the septic system drainfield. This biofilter attempts to simulate filter media placement below the infiltrative surface of drainfield product (FDOH, 2010).

Figure 2 - PNRS II Test Facility System Schematic



Source: FDOH, 2011
- PNRS II Test Facility Data Summary Report 4

Operation of PNRS II is ongoing but effluent testing indicates TN reduction in Stages I - IV is dependant upon the media composition of each biofilter. A summary of TN removal for each group follows.

- **Group I: Single Pass two-stage filtration** – The most effective TN removal biofilter configuration is an unsaturated nitrifying biofilter composed of 15 inches of expanded clay followed by a saturated denitrifying biofilter composed of 10% limestone, 30% sulfur, and 60% expanded clay. Mean TN measured in the effluent is 1.1 mg/L (FDOH, 2011c).

- **Group II and Group III: Recirculating unsaturated nitrifying biofilter followed by saturated denitrifying biofilter** – Group II and III are combined because effluent from Group II unsaturated biofilters is pooled then further treated by Group III saturated biofilters. The lowest mean TN effluent was 1.0 mg/L. One Group II filter pair did not pool effluent between the unsaturated and saturated biofilters. However, effluent testing was not complete due to a clog (FDOH, 2011c). Although recirculating filters are slightly more effective at removing TN than single pass filtration, recirculating filters do not meet the definition of "passive" in regards to the number of effluent pumps required for operation (FDOH, 2011c).

- **Group IV: Unsaturated in-situ biofilters:** Total nitrogen reduction was most effective in the simulated in-situ biofilter composed of 12 inches of sand underlain by 12 inches of media composed of 45% expanded clay, 35% lignocellulosic material, and 20% sulfur. The mean TN content of effluent from this biofilter is 1.1 mg/L (FDOH, 2011c).

In-field testing of passive nitrogen reduction methods is planned at various home sites throughout the state and in the Florida Keys once Passive Nitrogen Removal Study II is complete.

Summary

Safe and effective sewage disposal historically has been problematic in the Florida Keys due to lack of space, unsuitable or non-existent soil, and the porous nature of the Key's geology. Several studies have shown that sewage disposal methods are resulting in nutrification of the normally oligotrophic coastal water surrounding the Keys. Bacteriophage tracer studies indicate that sewage is reaching the coastal waters in as little as 7 hours after being flushed down a toilet that was served by an onsite sewage treatment and disposal system (septic system) (Paul et al., 1995). Green Flouresbrite spheres ranging in size from 0.7 to 1 micrometer in diameter were also flushed and observed in a monitoring well 7 hours after flushing and a green phosphorescing cloud was observed in a canal near the septic system 33 hours after flushing (Paul et al., 1995). A similar tracer study was performed on a Class 5 injection well with the bacteriophage being detected at a test point in Florida Bay located 167 meters away from the injection well (Paul et al., 1997). Furthermore, significant nutrient enrichment was measured in groundwater extracted from monitoring wells adjacent to residences served by septic systems (LaPointe et al., 1990).

The Florida Department of Health is currently studying passive nitrogen reduction strategies that can be employed to reduce TN in septic system effluent. The definition of passive has been defined so that no more than one effluent pump can be used in nitrogen reducing systems. To date, the method that shows the most promise is single pass two-stage filtration consisting of unsaturated nitrification biofilters followed by saturated anoxic denitrification biofilters. Testing shows this system is capable of reducing TN by more than 97 percent (Smith et al., 2008).

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