EXPERIENCES FROM FLORIDA’S NUTRIENT REMOVAL ONSITE SEWAGE TREATMENT AND DISPOSAL SYSTEM DESIGNS

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ABSTRACT
In Florida, onsite sewage treatment and disposal systems (OSTDS) designed to remove nutrients (nitrogen and/or phosphorus) generally belong to the permitting category of Performance-based Treatment Systems (PBTS), which was established in 1998. For such systems, Florida’s regulations require that a permit application include a design by a professional engineer, a biennial operating permit, and a system maintenance contract. Statutory requirements for performance levels for nutrient removal systems were established based on the results of a study conducted in the Florida Keys in the late 1990s. The Keys study evaluated several technologies installed in parallel and operated under controlled conditions at a test facility. The study concluded that performance levels of 10 mg/L of total nitrogen (TN) and 1 mg/L of total phosphorus (TP) were achievable, and thus these limits were incorporated into the statutory requirements for onsite sewage system in the Florida Keys. Design practices were heavily influenced by this study, with engineers relying on or extrapolating from limited test data. The result was a de-facto, deemed-to-comply approach in the Florida Keys that relied on an effluent-concentration based design approach. Monitoring focused on ensuring that systems were maintained and operating properly. With increasing interest in nutrient reduction in other areas of the state came increasing interest in the performance and evaluation of alternative technologies. Over the last ten years, several monitoring studies in Florida have provided additional information on the field performance of septic systems, aerobic treatment units, and nutrient removal systems. These studies illustrated the limitations of the effluent-concentration based design approach. For TN, influent concentrations and operational variability were higher than assumed in the applied designs. For TP, the main problem appeared to be the actual adsorption life span of treatment media designs was not assessed. This presentation will review some experiences with nutrient removing onsite sewage systems in Florida.

INTRODUCTION
Reducing nutrient contributions of nitrogen and/or phosphorus from OSTDSs is of importance in watersheds where surface waters exhibit elevated nutrient levels and the density of onsite systems is high. Reducing nutrient contributions from OSTDSs may consider design, certifications, training, operation, and surveillance. Florida permits explicit nutrient reducing systems as PBTSs. Regulations require that the application include a pre-installation design by an engineer and a post-installation operating permit and a maintenance contract agreement. The objective of this paper is to provide an overview of experiences in Florida with the design of nutrient reducing systems. Reviewing previous studies and their application to design, I will discuss the permitting category, design goals and assumptions, practices, and review results of assessments of the performance of such systems.

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PERFORMANCE-BASED TREATMENT SYSTEMS (PBTS)
The permitting category of PBTS is characterized by several requirements that go beyond a traditional septic tank and drainfield system. The PBTS category is defined in Florida’s regulations (Florida Department of Health, 2013):

“Performance-based treatment system – a specialized onsite sewage treatment and disposal system designed by a professional engineer with a background in wastewater engineering, licensed in the state of Florida, using appropriate application of sound engineering principles to achieve specified levels of CBOD₅ (carbonaceous biochemical oxygen demand), TSS (total suspended solids), TN (total nitrogen), TP (total phosphorus), and fecal coliform found in domestic sewage waste, to a specific and measurable established performance standard. This term also includes innovative systems.”

While the definition indicates a PBTS is to be designed by an engineer with a background in wastewater engineering, there is no formal training requirement particular to onsite systems or mechanism in place to evaluate the “background in wastewater” of practicing engineers. The PBTS definition also includes the term “innovative systems”. As defined in Florida Statutes (FS) section 381.0065(2) (h), an innovative system is one “that, in whole or in part, employs materials, devices, or techniques that are novel or unique and that have not been successfully field-tested under sound scientific and engineering principles under climatic and soil conditions found in this state.” The innovative system reference to sound engineering principles is also contained in the definition of a PBTS. For the components that an engineer can utilize in a design, this leads to a distinction between innovative and non-innovative treatment components.

A second feature in PBTSs, is the specificity of treatment performance. As part of the design the engineer defines the treatment goals as “specific and measurable established performance standard.” This includes “specified levels of CBOD₅ (carbonaceous biochemical oxygen demand), TSS (total suspended solids), TN (total nitrogen), TP (total phosphorus), and fecal coliform found in domestic sewage waste”, as referenced in Florida Administrative Code (FAC) section 64E-6.026(10). Florida regulations established several specific sets of combinations of performance standards that reflect the terminology used in large wastewater treatment systems (i.e., secondary, advanced secondary, and advanced wastewater treatment standards) (Rule 64E-6.026(1),(2),(12), FAC).

A third feature of PBTS standards, is the requirement for the owner of the system to obtain an operating permit and maintenance agreement with entities authorized by the engineer and manufacturer of the system (Rule 64E-6.027(6), FAC). In order to become a maintenance entity (ME), a service provider must obtain an ME service permit, and to obtain the ME service permit, the service provider has to document to the Florida Department of Health (FDOH), that they possess manuals, have adequate staffing, access to spare parts, and that they have received training and the manufacturer’s approval to perform service on their system. As part of the operating permit, annual inspections are performed by FDOH. The operation and maintenance requirements are very similar to Florida’s requirements for aerobic treatment units (ATUs) certified to National Sanitation Foundation International (NSF) standard NSF-40, which have been approved in Florida since 1971. The ongoing regulatory inspections and maintenance visits could potentially but not always include effluent sampling. Please note sampling requirements were not in place for the systems discussed in this presentation.
Florida Statutes established performance based treatment systems in 1998 following recommendations of a multi-year study on the design and performance of onsite systems in the state (Ayres Associates, 1993). These included the development and implementation of a performance-based program and establishment of measurable performance standards for the protection of water quality (Ayres Associates, 1993). PBTS design performance criteria allow for permitting of systems where a conventional septic system would not be permissible. An example for this is where the use of a PBTS will permit the increase in the allotted sewage per lot area. (Section 381.0065(3)(a), FS, and Rule 64E-6.028, FAC).

**DESIGN ASSUMPTIONS ABOUT INFLUENT**

Baseline or conventional system treatment tank effluent standards, provide a point of comparison for higher treatment levels. These indicate the concentrations expected out of a septic tank. The concentration according to Florida’s PBTS baseline system standards (Rule 64E-6.026(3)(a), FAC) are shown in Table 1. The previously mentioned Ayres Associates (1993) study measured septic tank effluent concentrations multiple times from eight onsite systems in Florida. Their values are also included in Table 1. The comparison shows that except for CBOD₅, the baseline treatment standard value is in the middle of the range of measured septic tank effluent concentrations. This suggests that the baseline treatment standards describe an average or typical performance rather than the performance of any particular system.

Florida Keys sampling data from ATUs obtained from 2000 to 2001, the end of the sampling program, provided data on systems that were not particularly designed for nutrient reduction (Roeder and Brookman, 2006). There were significant differences between sample point locations. Overall median TN concentrations were 26 mg/L and TP concentrations were 7.8 mg/L (Table 1). Concentrations varied about three orders of magnitude. Compared to septic tank effluent, ATUs appeared to achieve some TN reduction (less than 50%) and limited TP reduction.

Table 1. Florida baseline (conventional) treatment system standards, results of septic tank effluent concentration measurements by Ayres Associates (1993) and results of ATU sampling in the Florida Keys (Roeder and Brookman, 2006).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CBOD₅ (mg/L)</th>
<th>TSS (mg/L)</th>
<th>TN (mg/L)</th>
<th>TP (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Treatment tank effluent (Rule 64E-6.026(3)(a), FAC)</td>
<td>≤240</td>
<td>≤176</td>
<td>≤45</td>
<td>≤10</td>
</tr>
<tr>
<td>Average (Range) of Concentrations (n=36) (Ayres Associates, 1993)</td>
<td>141 (111-181) (BOD5)</td>
<td>161 (64-594)</td>
<td>39 (36-54)</td>
<td>11 (7-15)</td>
</tr>
<tr>
<td>Median of ATU-samples in the Florida Keys (Roeder and Brookman, 2006)</td>
<td>5</td>
<td>32</td>
<td>26</td>
<td>7.8</td>
</tr>
</tbody>
</table>
Questions as to the best nutrient treatment achievable with onsite sewage treatment systems were raised in the 1990s, focusing on the Florida Keys (Keys) and its insufficient wastewater infrastructure. Water quality impacts from both nitrogen and phosphorus on coral reefs and associated marine sanctuaries were of particular concern. To address this, Ayres Associates conducted a multi-year and multi-phase study for the Florida Department of Health (Ayres Associates, 1998, 2000).

The researchers solicited a range of approaches to reduce nitrogen and phosphorus in the effluent of onsite systems. A test facility was built in the Keys and sewage from a nearby penitentiary facility was directed to several parallel treatment trains. Influent and effluent sampling points were used to compare the effectiveness of several approaches.

For nitrogen reduction, recirculation and cycling of aerators were two methods used to aerate the sewage and achieve denitrification. Figure 1 provides a summary of the observed performance of several treatment trains in the two phases of the study. Not all treatment trains remained in operation during both phases of the study. The second phase implemented several design modifications to refine and improve treatment options.

To increase denitrification, limited testing of carbon additions into an anoxic biofilter, after the aeration and recirculation steps, was performed during the second phase of the study. Carbon addition, after effective nitrification/denitrification, was the only treatment train that achieved a 10 mg/L TN concentration outright.

The OWNRS study concluded that total nitrogen reductions in excess of 70% were achievable without carbon addition using biological nitrification and denitrification. The best treatment unit without carbon addition reached close to 10 mg/L TN effluent concentrations. The study also concluded that onsite systems were not capable of achieving an effluent concentration of 3 mg/L, the advanced wastewater treatment standard. The study indicated that a recirculating sand filter would be much less effective than some aerated treatment units. Test experience with lined drip irrigation systems indicated that TN reduction provided by such drainfields was not markedly different from conventional drainfields, even when a saturated zone in the lined drip irrigation beds provided for additional denitrification (Figure 3a).

For phosphorus reduction, the study focused on adsorption media. The two varieties of adsorption media used were brick chip dust and light expanded clay aggregate. An improved manufactured version of the latter, Filterlite-P, was studied in the second phase of the study. The study looked at two sets of treatment trains. Influent from a mixing tank was dosed to a septic tank (ST-2) or to a recirculating sand filter with an anoxic biofilter (RSF/ABF). The effluent of the septic tank was dosed to lined drip irrigation drainfield beds constructed with either of the two adsorption media or sand. Effluent from the recirculating sand filter was dosed to an unlined drip irrigation drainfield beds constructed with the same media. Figure 2 shows the average TP concentrations for several treatment trains during the two phases. The study concluded that treated effluent concentrations of 1 mg/L of TP were achievable using the engineered media and drip irrigation design. The study evaluated the possible life expectancy of the adsorption media by taking cores from a treatment
media bed and determining the amount of adsorbed phosphorus. An estimated lifetime of less than ten years was calculated based on the breakthrough velocity of the media installed in the drip irrigation drainfield systems.

Figure 1. Average and standard deviations for total nitrogen from the Florida Keys Onsite Wastewater Nutrient Reduction Study (based on Ayres Associates, 1998, 2000) (IMT=influent mixing tank; FAS=Bio-Microbics FAST; FAS-Carbon= FAS with subsequent carbon addition; ST-2=septic tank feeding lined drip irrigation systems; LSAND=lined sand drip irrigation bed; LLECA= lined LECA drip irrigation bed; LBrick= lined brick dust drip irrigation bed; RSF-ABF= Recirculating sand filter with anoxic biofilter feeding; Usand=unlined sand drip irrigation bed; ULECA= unlined LECA drip irrigation bed; RBC-ABF= rotating biological contactor with anoxic biofilter; CFCR=Continuous feed cycling reactor).
Figure 2. Average results and standard deviations for total phosphorus of the Florida Keys Onsite Wastewater Nutrient Reduction Study (based on Ayres Associates, 1998, 2000) (IMT=influent mixing tank; FAS=Bio-Microbics FAST; ST-2=septic tank feeding lined drip irrigation systems; LSAND=lined sand drip irrigation bed; LLECA= lined LECA drip irrigation bed; LBrick= lined brick dust drip irrigation bed; RSF= Recirculating sand filter; RSF-ABF= Recirculating sand filter with anoxic biofilter feeding unlined drip irrigation beds; USand= unlined sand drip irrigation bed; ULECA= unlined LECA drip irrigation bed; UBrick=unlined brick dust irrigation bed (n=1))

Figure 3 reproduces drawings of the lined and unlined drip irrigation drainfield beds constructed by Ayres Associates (1998). The lined drip irrigation drainfield beds included both a one-foot saturated, and a two-foot unsaturated media layer. Most of the information on treatment effectiveness, in particular for TP, was derived from these systems. The unlined drip irrigation drainfield systems included two feet of unsaturated media, received effluent from the recirculating sand filter that was already removing a large fraction of TP, and provided a smaller number of samples.

The results of the OWNRS study influenced the requirements for OSTDSs in the Florida Keys. Legislation in 1999 required a “level of treatment that will produce an effluent that contains not more, on a permitted annual average basis, than the following concentrations:” total nitrogen of 10 mg/L and total phosphorus of 1 mg/L (Laws of Florida Ch. 99-395).
Subsequently, in the 2000 report on the second phase of the OWNRS study, Ayres Associates concluded in part:

“Results indicated that the systems evaluated provided excellent treatment but no individual system was capable of meeting all effluent standards currently in place for the Florida Keys (10 mg/L CBOD5, 10 mg/L TSS, 10 mg/L TN, and 1 mg/L TP). A combination of various unit processes evaluated would achieve treatment performance by onsite wastewater systems, which meets current effluent standards. A biological treatment system which incorporates nitrification/denitrification (>70% TN reduction) and discharges to an engineered media SDI bed should consistently meet the current Florida Keys standards for CBOD5, TSS, TN and TP.”

In 2001, the requirements changed to apply to fewer establishments (Laws of Florida Ch. 2001-337), but retained the same treatment levels for systems anticipated to remain in permanent service (OWNRS). For temporary systems, interim standards required the installation of an ATU. In 2001, legislation also changed the fees for operating permits for ATUs and PBTSs. Until the year 2001, health department inspectors performed some sampling of PBTSs. With the diminished fees, this sampling program was abandoned, and the annual or semi-annual sampling assumed in the OWNRS-study reports did not take place.

**DESIGN PRACTICES**

With treatability assured, measurable performance levels and requirements established, and treatment systems categorized as PBTS, engineers were in a position to begin designing performance-based treatment systems in early 2000. A key question was not clearly addressed: what is required for an engineer to show to document or validate that a PBTS will meet the design treatment standards? Initially, the Department’s guidance for engineers and department staff was fairly broad and did not address this question. In practice, the OWNRS study became more of a point of comparison. The OWNRS study showed that adsorption media could be used to meet phosphorus treatment standards for a limited lifespan. The study also demonstrated that some ATUs could achieve 70% TN reduction and approximate the 10 mg/L effluent concentrations treatment standard. Using this approach, engineers selected treatment system components, which for assumed influent concentrations, had met the desired effluent concentrations. Margins of safety
were not included in the designs. In the following two sections, I will present examples of how design practices were developed to address the challenges created by the initial design and point-of-comparison approach.

**Phosphorus**

The OWNRS study intended the phosphorus reduction media to be installed as part of a drip irrigation drainfield. Two concerns resulted in the development of design variants. First, the challenge to design for small rocky lots with relatively small areas available for the installation of the drainfields. To address the small lot situation, effluent disposal was achieved by injection well. The Florida Keys are the only area in the state where such disposal of onsite sewage system effluent is permitted by regulations. Second, the prospect of replacing a drainfield periodically to account for adsorption media requirements was not appealing. Both considerations lead to adsorption media filter system installation in tanks.

Configuration of tank-based systems had strong similarities to a mineral aggregate filter configuration common in the Keys. This single pass mineral aggregate filter was a requirement for ATUs discharging to injection wells. For PBTS discharging to an injection well, a tank with phosphorus treatment media became a substitute for the mineral aggregate filter. The tank media filter utilized a gravity distribution system to evenly distribute the effluent over the treatment media in the main compartment. The treatment media was underlain by an underdrain system of gravel and perforated pipe. In the second compartment (a large diameter pipe when the filter was constructed in a single compartment tank), a pump was installed to maintain the treatment media of the first compartment partially unsaturated. In some systems, the pump compartment also contained a tablet chlorinator to achieve basic disinfection, when required before discharge to an injection well. Compared to the OWNRS study’s tested configuration (Figure 3a), commonalities included a largely unsaturated, 2 foot deep layer of adsorption media. Differences between the tank-based configuration and drip irrigation drainfields were the application of a higher loading rate and the use of a gravity perforated pipe distribution system instead. The higher loading rate was typically accounted for by proportionately adjusting the expected life span of the media.

Another system variant utilized an up flow saturated media filter. This concept was similar to an up flow constructed wetland. The specially manufactured expanded clay aggregate had been used in such configurations. In the up flow configuration, the pretreated effluent was distributed through a system of perforated pipes at the bottom of the filter. The effluent flowed upwards through the saturated filter media. Above the filter media was a water layer. The water above the media moved through a set of perforated pipes to the outlet of the tank. The commonality with the study’s tested system was the utilization of treatment media and that the lined tested system also contained some saturated media. Vertical upwards flow could potentially improve equal distribution. The higher loading rate was typically accounted for by basing the expected life span on adsorption capacity.

Further variations occurred in treatment media. The OWNRS study had assessed two versions of light-expanded clay aggregates. As the manufacturer changed the properties of this material, two varieties were installed: AOS and a version of LECA distributed as Filterlite-P. In rare cases chemical precipitation systems were designed using Mid-floc, a technology transferred without further evaluation from larger wastewater treatment plants.
Nitrogen

The OWNRS study had shown that one evaluated treatment system was capable of reaching close to 10 mg/L TN effluent concentrations. How would engineers go about designing treatment systems to meet a specific and measurable performance level of 10 mg/L? Eventually, the criterion for an acceptable design became based on technology and manufacturers. If test center data for the technology showed a treatment system achieved 10 mg/L, then it could be used by engineers. Figure 4 shows effluent concentrations and TN reduction for several technologies for which Environmental Technology Verification (ETV) data or other test center data were compiled by the author in the mid-2000s. For a given influent concentration, the relationship is linear, the higher the treatment effectiveness, the lower the effluent concentrations. The data from ETV tests, which were performed at very similar influent concentrations, illustrates this relationship. Variations in the influent concentration shift such a relationship. Generally, systems that achieved 10 mg/L effluent concentrations also achieved greater than 70% TN reduction. Treatment systems for nitrogen reduction were a subset of standard NSF-40 certified ATUs or their variants.

PERFORMANCE ASSESSMENTS

How well do PBTSs work? Given the lack of a comprehensive monitoring and sampling program, the answers were difficult to document. In 2005, the Department initiated a project to evaluate the performance of advanced treatment systems in the Keys. With additional funding through the United States Environmental Protection Agency’s (EPA) non-point source pollution control grant program, a state-wide project was implemented in 2007-2011, with a pilot phase in the Keys to assess advanced treatment systems (i.e., ATUs and PBTS). The pilot phase evaluated variability of treatment system effluent and validated sampling protocols. It also provided data on the performance of treatment systems in the Keys.

Figure 5 shows influent and effluent concentrations of several ATUs (interim) and systems designed for phosphorus reduction (OWNRS). The data suggested that influent concentrations of TP were frequently much higher than 10 mg/L. Effluent concentrations of OWNRS that were supposed to reach 1 mg/L, did so only in a few cases. Effluent TP concentrations from OWRSNs were generally lower than from ATUs. The average reduction of all OWNRS compared to the average influent concentration estimated was 57%. Comparing effluent and influent concentrations for those OWNRS for which both were measured at the same time, the reduction estimated was 54% (Roeder and Brookman, 2009). An analysis of data from this phase with regard to treatment approach is included in Roeder (2011). The treatment approach was categorized based on permitting information. Results from system sampling events by phosphorus treatment approach are summarized in Table 2.
Figure 4. Relation between the fraction of TN removed and the effluent concentration measured during nitrogen reduction tests as part of Environmental Technology Verification (ETV) testing or in conjunction with NSF-40 testing at several test centers. (Data compiled from a variety of test center reports). OWNRS/FAST refers to the results of the best treatment system during the OWNRS study.

Table 2. Mean and median concentrations of 2007-2009 samples from systems that included a phosphorus reduction step. AOS = light expanded clay aggregated modified for phosphorus adsorption; LECA=Filterlite-P light expanded clay aggregate; Mid-floc=chemical additive.

<table>
<thead>
<tr>
<th>TP (mg/L)</th>
<th>Brick chip unsaturated</th>
<th>Brick chip not determined</th>
<th>AOS not determined</th>
<th>LECA saturated</th>
<th>LECA not determined</th>
<th>Mid-floc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>5.6</td>
<td>6.8</td>
<td>6.8</td>
<td>4</td>
<td>1.5</td>
<td>10.4</td>
</tr>
<tr>
<td>Median</td>
<td>4.6</td>
<td>6.2</td>
<td>8.9</td>
<td>4</td>
<td>1.2</td>
<td>8.75</td>
</tr>
<tr>
<td>Number of Samples</td>
<td>36</td>
<td>12</td>
<td>9</td>
<td>10</td>
<td>6</td>
<td>8</td>
</tr>
</tbody>
</table>
Figure 5. Total Phosphorus Concentrations from several systems in the Florida Keys. OWNRS (=onsite wastewater nutrient reduction system) are designed for phosphorus reduction, Interim systems are ATUs, sometimes with mineral aggregate filter. Influent concentrations are from systems where influent could be sampled.

Results for phosphorus reduction varied widely but did not meet the treatment goal of 1 mg/L. The lowest effluent concentrations were observed for specially manufactured light expanded clay material. But even the mean of these results exceeded the target of 1 mg/L TP. Several reasons may combine to bring the observed results: configurations were initially not functional or the treatment systems failed due to maintenance issues. Anecdotal reports suggest that the brick chip material has a tendency to stick together and become a less permeable block, which would allow short circuiting (W. Brookman; M. Repasky, personal communication). The adsorption capacity may have been reached without the treatment media being replaced by the maintenance entity. For the chemical additive treatment approach, the most likely explanation was that no chemical was added during operation.

Figure 6 summarizes nitrogen results for the same phase of the study, as Figure 5 (Roeder and Brookman 2009). Similar to the situation with phosphorus, the specific goal of the treatment system (TN=10 mg/L) is only rarely achieved. In contrast to phosphorus concentrations, where the influent appeared to be only slightly higher than during the OWNRS study, total nitrogen concentrations in the pretreatment tank were much higher than the earlier studies had indicated,
with a median concentration of around 80 mg/L. Only one of the influent concentrations samples shown in Figure 6 was less than 45 mg/L. With higher influent concentrations, a 70% TN reduction resulted in higher effluent concentrations than with lower influent concentrations. Higher effluent concentrations tended to be associated with higher Total Kjeldahl nitrogen (TKN) concentrations (red and yellow dashed circles in Figure 6). The highest effluent TN concentrations consisted nearly exclusively of TKN. These results suggested two conclusions: If 70% TN reduction describes the performance of a treatment system, higher influent concentrations makes reaching and effluent concentration of 10 mg/L less likely. For a subset of the systems sampled, nitrification was a limiting step for nitrogen reduction and, for these systems, effluent concentrations tended to be particularly high.

Around the time of the pilot test in the Florida Keys, a project was performed for the Water Environment Research Foundation (WERF) that aimed at measuring the composition of the modern septic tank influent and effluent. This study included six systems located in northern Florida, along with others in Minnesota and Colorado. Table 3 summarizes the results of that study (Lowe et al, 2009), along with results of the pilot study in the Keys (Roeder and Brookman, 2010). In both cases, concentrations of TN were higher than previous design assumptions, but Lowe et al (2009) reported a concentration that is about half-way between earlier design assumptions and the pilot study in the Keys (Table 3).

In 2006, Wakulla County, a northern Florida county, adopted an ordinance requiring nitrogen reducing onsite systems (Wakulla County, 2006). This ordinance used language similar to the Florida Keys requiring the installation of “performance-based septic systems that can produce a treatment standard of 10 mg/L…” In 2008, the Florida Department of Environmental Protection (FDEP) scoped a study to assess the performance of systems designed according to the Wakulla ordinance. Harden et al (2010) reported on the results. One finding was that a substantial fraction (39%) of the systems were not operating as designed, largely to being switched off. In three cases, electrical connections were never completed. Among the systems that at first glance appeared to be operating, the average effluent TN concentrations of a repeatedly sampled set of eight PBTS, as well as a once-sampled set of 27 PBTS, were about 30 mg/L. Comparison to the WERF study (Lowe et al., 2009) with an average effluent concentration of 64 mg/L indicated a reduction of 55% (Figure 7). Sample results showed similar average TN results for high or low fractions of TKN.

The 2007-2011 study by the Department included sampling of ATUs and PBTSs. The project report and summary reports contain detailed information about methods and system selection (Roeder and Ursin, 2013a,b). The overall results were similar to the results reported by Roeder and Brookman (2006) for ATUs in the Florida Keys. Median TN effluent concentrations were 30 mg/L (compared to 25 mg/L) and median TP concentrations were 7.5 mg/L (compared to 7.8 mg/L). In contrast to earlier performance assessments discussed above, influent samples (pretreatment tank or upstream samples with low dissolved oxygen and nitrate concentrations) indicated median TN influent concentrations (45 mg/L) were still within the upper limit of baseline treatment system standards.
Figure 6. TN (influent and effluent) and TKN (effluent) concentrations for sampling events for several OWNRS and interim systems in the Florida Keys (Roeder and Brookman, 2009).

Table 3. Pretreatment or septic tank effluent concentrations from a sample of systems in the Florida Keys and from a sample of septic systems in Colorado, Florida, and Minnesota.

<table>
<thead>
<tr>
<th>Median Concentrations</th>
<th>cBOD$_5$ (mg/L)</th>
<th>TSS (mg/L)</th>
<th>TN (mg/L)</th>
<th>TP (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Influent (Pretreatment tank concentration) (TKN/TN &gt;=0.9 TSS&lt;1,000 mg/L) (Roeder and Brookman, 2010)</td>
<td>90 (n=52)</td>
<td>68 (n=52)</td>
<td>74.4 (n=52)</td>
<td>10 (n=51)</td>
</tr>
<tr>
<td>Septic Tank Effluent (Lowe et al. 2009)</td>
<td>216</td>
<td>61</td>
<td>60</td>
<td>9.8</td>
</tr>
</tbody>
</table>
Data collected included those needed for an assessment of the operational status of the systems. Status was assessed for items such as the apparent availability of power, the operation of an aerator, if present, and the presence of sanitary nuisances. Lack of power was concentrated in systems that served apparently vacant homes. Operational systems showed significantly lower TKN and TN (and cBODs) effluent concentration than non-operational ones. Figure 8 summarizes TN concentrations for the influent overall and effluent concentrations from operational systems. Effluent concentrations were grouped by treatment product line and sorted by median effluent concentrations. Each system installation was only represented by one sample. Median effluent concentrations range from 60 mg/L to 13 mg/L. Product line 23 performed the worst, with median effluent concentrations of 60 mg/L, indicating no appreciable TN reduction. This product line was a Florida variant of a recirculating media filter. Other treatment systems performed better, with average effluent concentrations in the 20 mg/L to 30 mg/L range. Some of the product lines, in particular 8, 27, and 31 were permitted either as ATUs or PBTS. A comparison of effluent concentrations and the applicable treatment standard of each treatment system installation indicated that the more restrictive the permitted treatment standard, the higher the fraction of treatment systems that did not achieve the standard. Given that the different treatment standards apply to systems that are largely identical, this was to be expected.
DISCUSSION

The most stringent performance standards for TN and TP in Florida exist in the Florida Keys with required effluent concentrations of 10 mg/L and 1 mg/L, respectively. The design and permitting of PBTS to these standards is based on several practices, or implicit assumptions. One assumption is that influent concentrations are below 40 mg/L TN and 10 mg/L TP. A second assumption is that the effluent concentrations from previous treatment system testing are transferable, with limited adjustment, to the designs for individual field sites. Monitoring and replacement of treatment media is also assumed. Systems rarely met specific and measurable performance standards during the assessments summarized above. Reasons appeared to be different for TN and TP.

For TP, typical influent concentrations remained similar in all of the assessments. Designing based on an influent concentration of 10 mg/L could be valid for an effluent concentration of 1 mg/L, i.e. an order of magnitude lower. Effluent concentrations in most cases were closer to influent concentrations than effluent goals. One possible explanation is that the adsorption capacity of the treatment system was exceeded. Replacement of treatment media could solve this issue. To identify the necessity media replacement, monitoring effluent would be necessary. Effluent monitoring would also be useful for detecting malfunctions related to lack of maintenance or installation variations.

Figure 8. Mean and standard deviation of effluent TN of operational treatment units, sorted by median of product lines with at least seven effluent sample results from systems assessed as operational.
For TN, influent concentrations were so variable that it was difficult to determine a typical influent concentration. All of the performance assessments presented indicated that the design assumption of influent concentrations below 40 mg/L is not representative of field conditions. Depending on the study, the typical influent concentrations varied from mid-40 to close to 80 mg/L (approximately a factor of two). The wide variability of effluent concentrations and influent concentrations has been observed elsewhere. For example, Heufelder et al (2007) summarized analyses of samples collected by maintenance entities in Barnstable County, Massachusetts, and discussed some reasons for their variability. Fraction of TN removed is one approach to reduce the influence of the variability of influent on effluent concentrations. In Massachusetts an effluent concentration of 19 mg/L TN is seen as equivalent to 50% reduction. This implies a similar influent concentration (38 mg/L) as what was tested in the Keys OWNRS study. In contrast, Maryland’s Bay Restoration Fund program assumes an influent concentration of 60 mg/L, while also looking for treatment systems that, on average, can achieve a 50% TN reduction (Maryland DEP, 2015). When reviewing field data for the same reduction goal, Massachusetts would look for effluent concentrations below 19 mg/L while Maryland would accept data below 30 mg/L.

Using the fraction of nitrogen reduced as performance measure has shortcomings from the perspective of being specific and measurable. To determine TN reduction for any particular site, influent and effluent concentrations would need to be measured, which is not feasible for many technologies and is also costly. Assuming a reference influent concentration and measuring many effluent concentrations from multiple systems, is necessary to estimate average treatment system performance. Such a measure can be used for field verification and comparative purposes (Maryland DEP, 2015). This is more feasible for technology review but provides less guidance for assessing the operation of a particular system at a particular site. Smaller in magnitude, but similar to the issue of transferability of effluent concentration values from test centers to the field, there is the question if such technology performance assessments are transferable from jurisdiction to jurisdiction. In the summary of Heufelder et al (2007), several product lines achieved a median TN concentration below 19 mg/L. For two of these (numbers 8 and 27), Florida system sample results exceeded 20 mg/L (Figure 8). It is difficult to pinpoint a cause for this difference (random variation, influent concentrations, temperature, maintenance, sampler, sampling techniques).

Depending on assumed influent TN concentrations, the measured typical effluent concentrations in the performance assessments indicate a range of performances. Effluent concentrations between 30 mg/L and 20 mg/L would translate to TN reductions between 25-50% and 50-67% (influent 40 mg/L and 60 mg/L, respectively). These reductions are lower than the 70% assumed in current design practices for TN reduction.

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LITERATURE CITED


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