Final Report to the Town of Falmouth

Performance of Eco-Toilets

Prepared by

Erika Woods

&

George Heufelder

of the

Barnstable County Department of Health and Environment

for

The Falmouth Water Quality Management Committee

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This project is funded in major part by the Town of Falmouth. Funding was authorized at the 2011 Spring Town Meeting to evaluate the efficacy, installation cost and public acceptance of both composting and urine-diverting toilets (eco-toilets). The Falmouth Water Quality Management Committee developed an Eco-Toilet Demonstration Program that offered a $5,000 incentive, plus the cost of a septic pump-out, to individuals willing to completely retrofit their home with eco-toilets. The Betterment Exemption Program was created to give property owners in the Little Pond Sewer Service Area the opportunity to avoid paying a betterment estimated at approximately $17,000 in exchange for retrofitting their homes with eco-toilets. Finally, the Town of Falmouth authorized $50,000 to cover the cost of eco-toilet graywater sampling for a period of one year.

The Barnstable County Department of Health and Environment staff conducted a rigorous eco-toilet monitoring program. The results and analysis for the eleven program participants are contained in this Final Report. Portions of the efforts described herein were funded by the Massachusetts Department of Environmental Protection with additional funds from the United States Environmental Protection Agency under a Section 319 competitive grant. Analyses and reporting regarding residual products and contributions by staff at the University of Maine School of Composting were funded using Section 319(b) funds.

For questions regarding this report or the analyses conducted herein, contact George Heufelder, Director of the Massachusetts Alternative Septic System Test Center (gheufelder@barnstablecounty.org).

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Thank you also to Sia Karplus and the Falmouth Water Quality Management Committee for providing background and water use data.

Introduction

As part of an overall wastewater management strategy, the Town of Falmouth has investigated the efficacy of diversion toilets or "eco-toilets" for the management of nutrient inputs to groundwater with specific reference to nitrogen and phosphorus. Eco-toilets are appliances that provide for the separation and routing of bodily waste (urine and/or feces and toilet paper) from residential sanitary wastewater, which is additionally comprised of "graywater" from various sources, such as sinks, showers or laundry wastewater. The investigation of eco-toilets in nitrogen sensitive areas stems from the theory that diverting nitrogen from wastewater reduces overall nitrogen entering groundwater via the septic tank-leach field system and may offer cost savings compared with other wastewater treatment and disposal methods. Two types of eco-toilets are investigated here: composting toilets and urine-diverting toilets.

Composting Toilets

Composting toilets convey bodily waste to a vessel or container where various organisms aerobically (in the presence of atmospheric oxygen) break down or stabilize waste. The technology is generally applied to meet goals of water reduction, community sanitation, nutrient reduction or nutrient reclamation and sustainability. There are various types and sizes of composting toilet configurations that range from simple collection bins to units with mechanical mixing and heating components and units with either single or multiple chambers. The treatment process in a typical small residential unit is carried out by an assortment of bacteria and fungi, and some authors have suggested that the breakdown is also assisted by an array of invertebrate species.[6] While the term "composting" generally refers to the breakdown of organic matter by thermophilic organisms, some investigators have noted that the higher temperatures necessary to achieve deactivation of pathogens (55°C for two weeks) are generally not achieved in small residential units, unless a system is augmented with nitrogen containing wastes.[6] Figure 1 shows a basic composting toilet design.

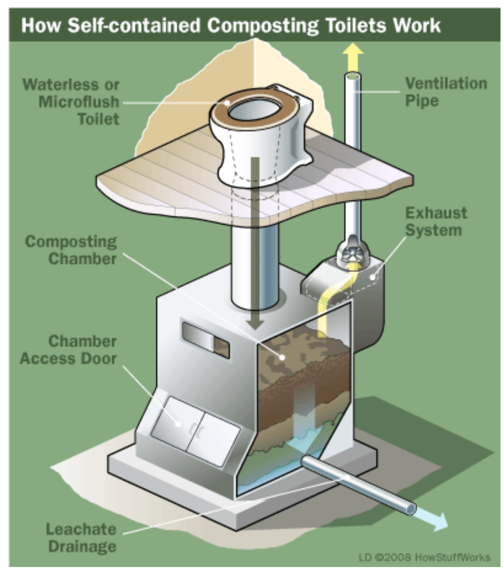

Figure 1. *Example of a composting toilet <http://home.howstuffworks.com/green-living/composting-toilet1.htm>*

Urine Diverting Toilets

Urine diverting toilets, in their most common application, divert the urine portion of bodily waste from the remaining wastewater. In context of this project, however, urine diversion can either be directed to a storage tank for further treatment or disposal, or to a composting toilet. The urine-diverting toilet fixture has two divisions that allow for the separation of fecal and urine deposits by positioning the body or directing the urine stream during elimination. Figure 2 shows a typical urine diversion toilet being used in one of the locations for this study.

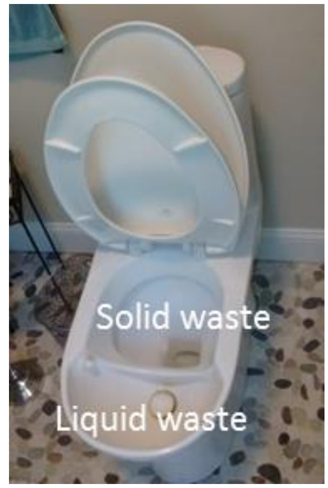

Figure 2. *Urine diverting toilet.*

Multiple Technology Use

Three of the properties installed both urine diverting and composting toilets. The bathrooms at these locations could not be served by gravity chute due to either elevation issues or factors surrounding the position of the composting bin within the dwelling.

This report will be broken into three sections to discuss each group of technologies individually.

Town of Falmouth Applications

Despite providing a well-advertised $5,000 incentive to any property owner in Falmouth, a septic system pump-out valued at approximately $300, and an opportunity to be exempted from a $17,000 betterment, participation in the program was limited. Of the over 20,000 water district customers that were notified via water bill notice, as well as several public advertisements and community events, 170 individuals reached out for further information about the program. Of these 170 people, nine participated in the program by retrofitting their homes with urine diverting and/or composting technology. Two other participating homes had been using composting toilets for years prior to the program. Over 50% of the individuals who showed initial interest, but did not take part in the program, cited home resale value as well as ongoing operation and maintenance requirements as reasons for not participating (see appendix 1 for further details).

This report describes results from eleven case studies where eco-toilets were installed and monitored for at least twelve months. See table 1 below for a summary of case study details for each property.

Case Study #	# Adults	# Children	Compost	UD	Dry Flush/ Gravity	Vacuflush	Details
1	2	-	✓		✓	✓	• 1 gravity toilet • 1 Vacu-flush
2	2	-	✓		✓		• 1 composting toilet
3	2	2	✓	✓	✓		• Urine directed into composting toilet • Solids from UD directed to septic system
4	2	-		✓			• UD only
5	1	-	✓		✓		• Self-contained unit
6	2	-	✓	✓	✓		• Urine directed to a composting toilet • Solids from UD directed to septic system • Per occupants, UD toilet used infrequently
7	2	-	✓			✓	• 2 Vacu-flush units directed into compost bin
8	2	2		✓			• UD only
9	2	2	✓				• Composting toilet installation predates this program
10*	4	-		✓			• UD only • Number of occupants doubled from 2 to 4 during the study
11	2	-	✓	✓	✓		• Discharge into existing septic is graywater only; no blackwater • Installation predates this program

Table 1. *Summary of details by case. *Case Study 10 was eliminated from statistical analysis due to the inconsistent nature of the results.*

Results

Below, results are presented for each case study, followed by a summary of the results combining similar situations. In each scenario, sampling was attempted on two occasions prior to installation of the eco-toilet so that pre-installation wastewater load calculations could be estimated. This was sometimes difficult due to the unique features of the existing septic systems, and in some instances, assumptions were required to approximate pre-installation conditions. In other cases, assumptions were required due to abnormally high readings or if the installation of the technology pre-dated the program. When necessary, assumptions relative to water use and influent nitrogen and phosphorus levels were used based on the following:

1. **Water use**
   A water use reduction of 20%, from 55 gpd per person to 44 gpd per person was assumed as a conservative value for calculations based on the following factors:
   - Per the United States Environmental Protection Agency (US EPA), regular flush toilets account for 30% of total household indoor water use.[2] Therefore, the maximum reduction that can be assumed for zero flow toilets (composting toilets) would be 30%.
   - The average water use reduction of all properties for which water use records were available in this study is 25.5%, while the median value is 27.0%.
   - A pre-installation value of 55 gpd per person was assumed based on MA DEP 310 CMR 15.203, *System Sewage Flow Design Criteria*; "The State Environmental Code, Title 5."[5] Title 5 specifies a design flow of 110 gpd per bedroom for a single-family dwelling with the assumption of two individuals occupying a bedroom.

2. **Total nitrogen and total phosphorus**
   Very few studies exist to demonstrate the typical effluent concentration of total nitrogen (TN) and total phosphorus (TP) from a residential, single family home. In this study, initial data assumptions were made based on Lowe, K.S. et al.[4] "Influent constituent characteristics of the modern waste stream from single sources." In situations where there were no initial samples taken, the mean values of all sites from Lowe, K.S. et al.[4]—64 mg/L TN and 10.3 mg/L TP—were utilized. In cases where the initial samples showed uncharacteristically high values, the maximum values—124 mg/L TN and 39.5 mg/L TP—for all sites from Lowe, K.S. et al.[4] were utilized.

Case Study 1: Home with Two Adult Occupants

Existing Onsite Wastewater Treatment

The existing system was composed of two cesspools in series. The first cesspool was essentially clogged and acting as a settling tank.

Composting Toilet Installation

A Phoenix composting toilet was installed using one micro-flush vacuum toilet located at the same level as the compost bin, and one "dry" toilet situated above the compost bin (figure 3).

Sample Collection and Analysis

Two samples taken at the outlet of the first cesspool prior to composting toilet installation exhibited Total Nitrogen (TN) concentrations of 61.0 mg/L and 48.0 mg/L, and Total Phosphorus (TP) concentrations of 7.8 mg/L and 6.0 mg/L.

Following installation of the composting toilet, 15 samples were collected over the course of one year. The mean concentration was 7.3 mg/L for TN (95% CI [6.7, 8.0]) and 0.9 mg/L for TP (95% CI [0.3, 1.5]) (figure 4).

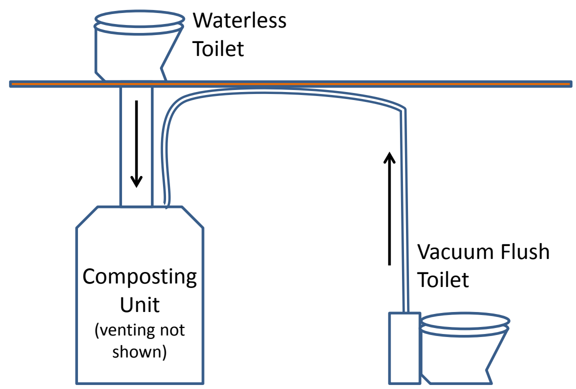

Figure 3. *Schemata of composting toilet equipped with one vacu-flush toilet.*

Outcome

Prior to installation of the composting toilet, the nitrogen load was 2.8 kg/person/year (6.1 lbs/person/year), with water use approximated at 36.9 gal/person/day. Following installation of the composting toilet, the nitrogen load was reduced to 0.25 kg/person/year (0.55 lbs/person/year), with water use approximated at 23.8 gal/person/day. This translates to an approximate water use reduction of 36%, with a 91% reduction in nitrogen load and a 91.9% reduction in phosphorus load (figure 5). A comparison of the overall initial mean concentrations of TN and TP from two pre-installation samples with 15 post-installation samples shows 86.1% and 87.4% respective removals.

Residuals

The composting toilet produced approximately 35 gallons of liquid residual "tea" in the calendar year 2014 and 46.5 gallons in 2015. Three samples of this tea were assayed for TN and TP, resulting in means of 3,590 mg/L and 480 mg/L respectively. This equates to an approximate nitrogen load of 0.5 kg/person/year (1.0 lbs/person/year) in 2014 and 0.6 kg/person/year (1.4 lbs/person/year) in 2015. Of the approximate 5.1 kg (11.2 lbs) per year of nitrogen removed from the discharge, roughly 11% of the nitrogen load was removed with the compost "tea," leaving the remaining 89% lost to either volatilization or solid compost.

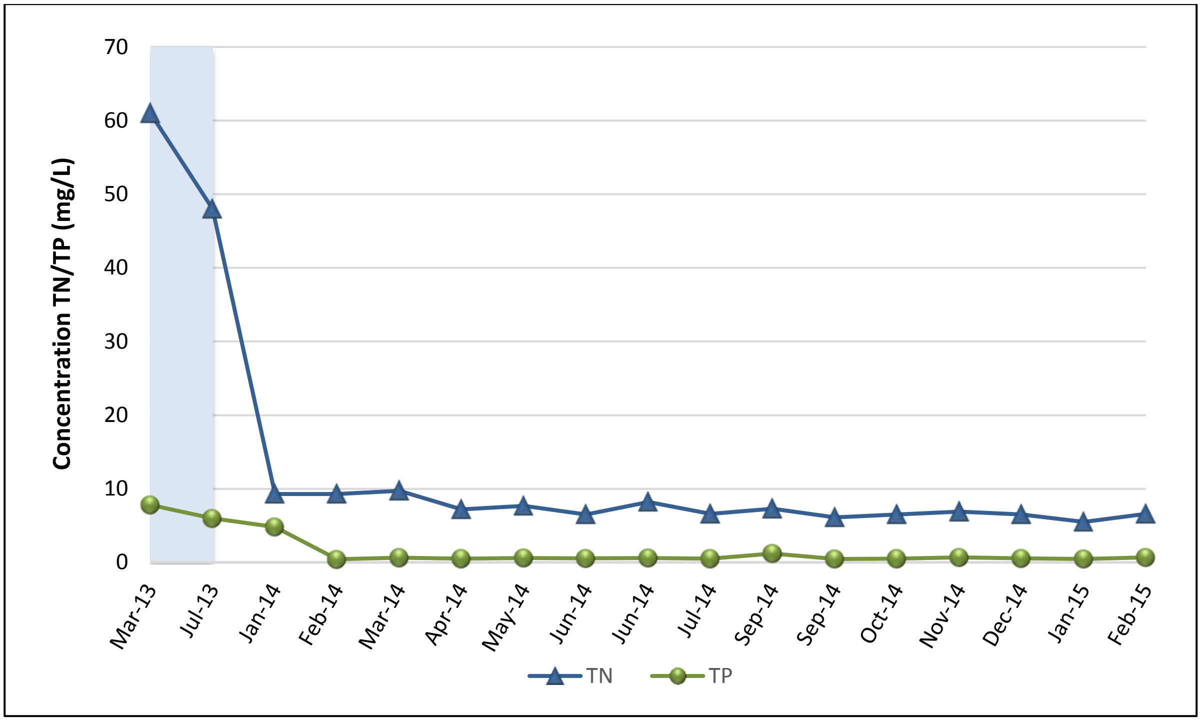

Figure 4. *Concentrations of TN and TP in wastewater from Case Study 1, a composting toilet-equipped residence. The shaded area denotes concentrations prior to compositing toilet installation and use.*

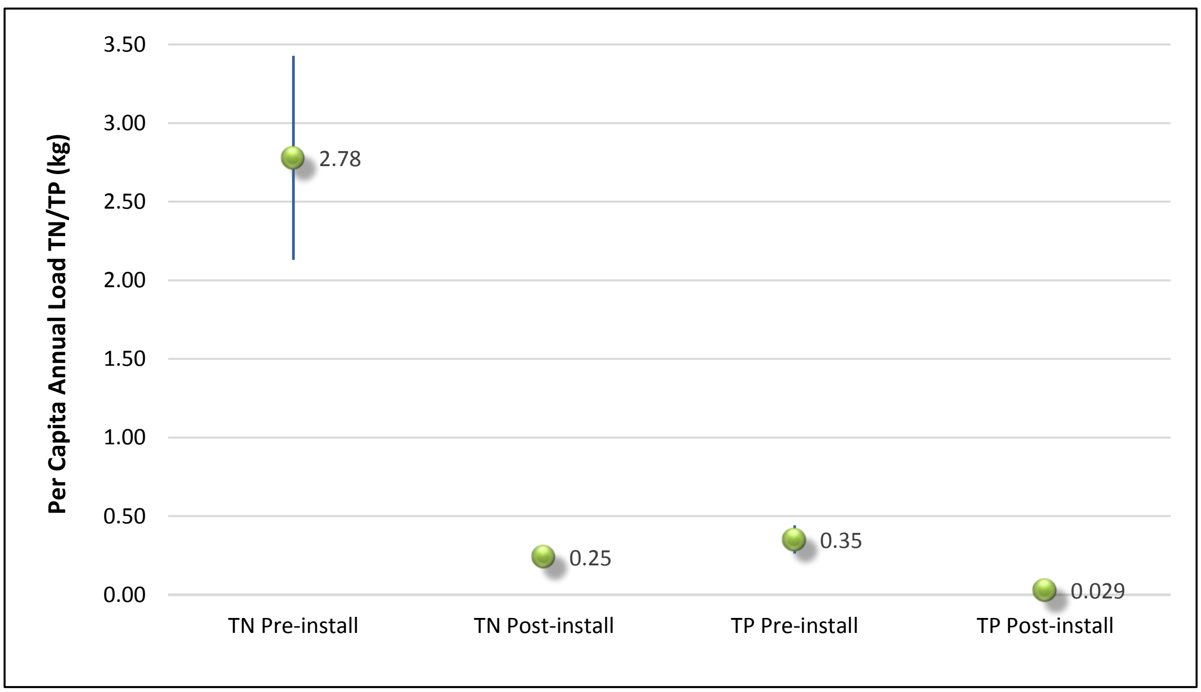

Figure 5. *Per capita TN and TP load reductions from Case Study 1, a composting toilet-equipped residence. Two pre-installation samples and 15 post-installation samples were taken. Means and a 95% confidence intervals are expressed for pre- and post-installation.*

Power Usage

Power usage for the composting toilet during 2014 was attributed to a vent fan, leachate pump, vacuum-flush unit and the battery charger (the vacuum-flush unit and fan operated on 12 volts dc). These components used approximately 114 kWh, which is an average of 0.31 kWh/day. Assuming a rate of $0.18/kWh, the electrical cost for operating the system was less than $21/year.

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Case Study 2: Home with Two Adult Occupants

Existing Onsite Wastewater Treatment

The existing septic system was comprised of a septic tank and soil absorption system.

Composting Toilet Installation

A Phoenix composting toilet was installed, using a standard "dry" toilet (figure 6).

Sample Collection and Analysis

The first pre-installation sample was taken at the influent side of the septic tank and yielded a TN value of 630 mg/L. It is important to note that the sampling location was not considered ideal as fresh solids entering the system may have disturbed the inflow and biased the sample. Following an excavation and exposure of the outlet side of the tank (and prior to the installation of the composting toilet), another sample was taken at the outlet side of the septic tank, but still yielded a high TN value of 340 mg/L.

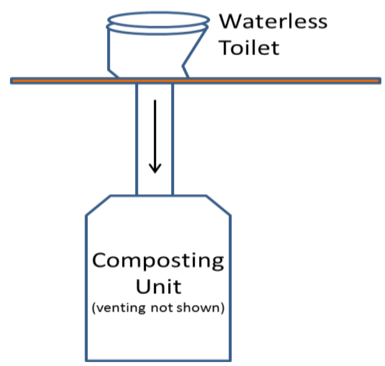

***Figure 6**. Schemata of simple installation with single "dry" toilet.*

A comprehensive review of wastewater characteristics from residential septic tanks[4] suggests that both pre-composting toilet samples may have been biased and represent unrealistically high values. Therefore, in the interest of more accurately estimating nitrogen load and load reduction, an initial concentration of 124 mg/L, which is the highest of 48 values found in Lowe, K.S. et al.[4], was used.

Further, two TP samples, also taken prior to installation of the composting toilet, showed similarly abnormal values of 27 mg/L and 42 mg/L. Since these values approximated the highest values observed by Lowe, K.S. et al.[4], the average of these values was used for the purpose of calculating TP load reduction.

Following installation of the composting toilet, 15 samples were collected over the course of one year. The mean concentration was 23.9 mg/L for TN (95% CI [20.8, 27.0]) and 2.4 mg/L for TP (95% CI [2.0, 2.8]) (figure 7).

Outcome

Using initial TN and TP concentrations of 124 mg/L and 34.5 mg/L respectively, the installation of the composting toilet yielded a TN concentration reduction of 80.7% and a TP concentration reduction of 93.1%. Since water use for Case Study 2 includes an unusually large volume for 2014, the owner was contacted and it is speculated that landscape irrigation was likely the cause for the high value. Assuming an initial water usage of 55 gpd per person and a conservative 20% water use reduction, as discussed previously, the total load reductions for TN and TP in Case Study 2 are calculated at 84.6% and 94.5% respectively (figure 8).

Residuals

The composting toilet produced approximately 100 gallons of liquid "tea" in 12 months of monitoring. Ten samples of this tea were assayed for TN and TP, resulting in means of 1,900 mg/L and 990 mg/L respectively. These volumes translate to approximately 0.7 kg (1.6 lbs) of nitrogen. Of the nearly 16 kg (35 lbs) of nitrogen removed by the composting toilet, approximately 4.5% was present in the compost "tea," with the remaining 95.5% either contained in the compost or lost to volatilization.

Power Usage

No direct power usage readings were taken during 2014. However, comparison with a similar model in Case Study 1 would suggest a power usage cost of less than 0.31 kWh/day. Assuming a rate of electricity charge of $0.18/kWh, the electrical cost for operating the system was less than $21/year.

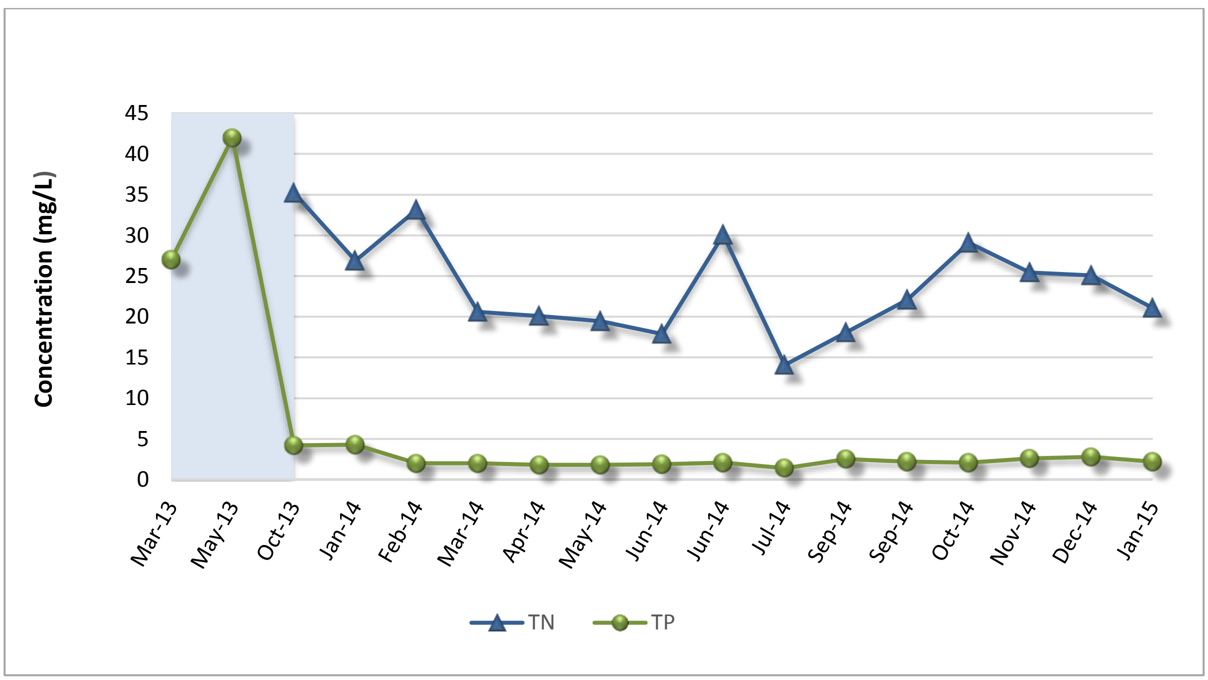

Figure 7. *Concentrations of TN and TP in wastewater from Case Study 2, a composting toilet-equipped residence. The shaded area denotes concentrations prior to composting toilet installation and use. Literature values (Lowe, K.S. et al.[4]) were assumed for pre-installation TN.*

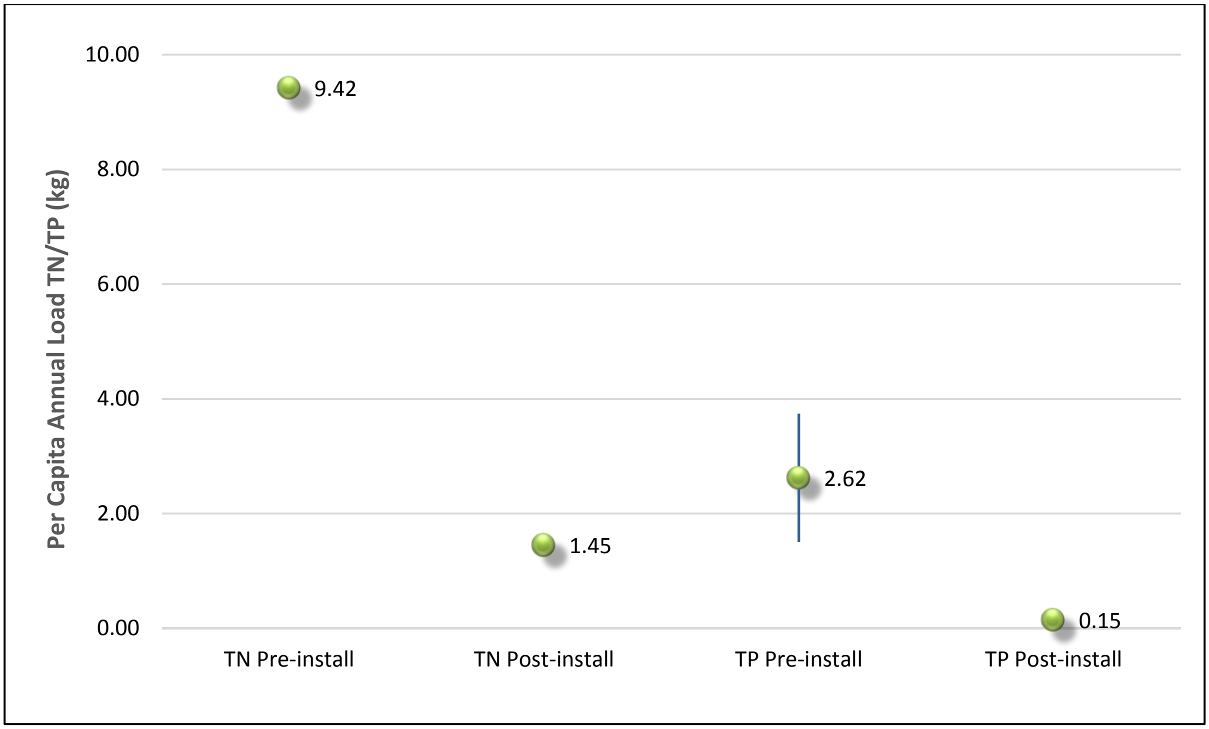

Figure 8. *Per capita TN and TP load reductions from Case Study 2, a composting toilet-equipped residence. Literature values (Lowe, K.S. et al.[4]) were assumed for pre-installation TN, and 15 post-installation samples were taken. Means and a 95% confidence interval are expressed for pre-installation TP, as well as post-installation TN and TP.*

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Case Study 3: Home with Two Adult and Two Child Occupants

Existing Onsite Wastewater Treatment

The existing system was comprised of a septic tank and soil absorption system.

Composting Toilet Installation

A Phoenix composting toilet was installed for the bathroom receiving a majority of the use. An additional bathroom was equipped with a urine diverting toilet that directed urine to the composting toilet (figure 9). Other sanitary waste from the toilet was directed to the septic tank-leach field system. In contrast to Case Studies 1 and 2, the residual graywater occasionally received fecal and attendant waste, which comprised some of the measured contaminants.

Sample Collection and Analysis

Samples were taken at the head of the septic tank, which was the only accessible location. It is important to note that the sampling location was not considered ideal as fresh solids entering the system may have disturbed the inflow and biased the sample. Nevertheless, care was taken to sample the middle layer of the septic tank at an elevation below the inlet sanitary tee.

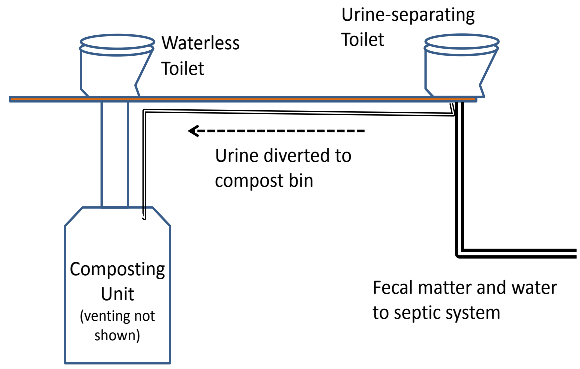

Figure 9. *Schemata of system with a composting toilet and another toilet capable of conveying fecal matter to the septic system.*

Considering the challenges of obtaining a representative sample, a nominal value of 64 mg/L TN and 10.3 mg/L TP concentrations were utilized based on the mean values observed by Lowe, K.S. et al.[4] Water data showed higher water usage for the residence than Case Studies 1 and 2, although per capita use was comparable.

Outcome

Using an initial TN concentration of 64 mg/L and a TP concentration of 10.3 mg/L and a post-installation mean concentration of 13.9 mg/L for TN (95% CI [16.5, 11.4]) and 1.3 mg/L for TP (95% CI [1.7, 0.9]), the calculated TN and TP concentration reductions were 78.2% and 87.5% respectively (figure 10). Prior to installation of the composting toilet, the nitrogen load per person per year was estimated at 4.9 kg/person/year (10.7 lbs/person/year), with an estimated phosphorus load of 0.78 kg/person/year (1.7 lbs/person/year). Since historic water use numbers were not available, a modest 20% reduction in wastewater volume was assumed as previously discussed. This yielded a conservative estimate of nitrogen load reduction to 0.9 kg/person/year (1.9 lbs/person/year) or 82.6%, and an approximate phosphorus load reduction to 0.08 kg/person/year (0.17 lbs/person/year) or 90.0% (figure 11).

Residuals

The composting toilet produced an estimated 460 gallons of liquid residual "tea" based on three months' worth of leachate collected within the 13 months of monitoring. Five samples of this tea were assayed for TN and TP and yielded means of 1,786 mg/L and 292 mg/L respectively. This volume represents approximately 3.1 kg/person/year (6.9 lbs/person/year) of nitrogen. Of the nearly 16 kg (35 lbs) nitrogen removed by the composting toilet, approximately 19.4% was present in the compost "tea," with the remaining 80.6% either contained in the compost or lost to volatilization. It should be noted that the annual volume was extrapolated from liquid residuals collected over a three month period. These results are high compared to other similar situations in this study.

Power Usage

No direct power usage readings were taken.

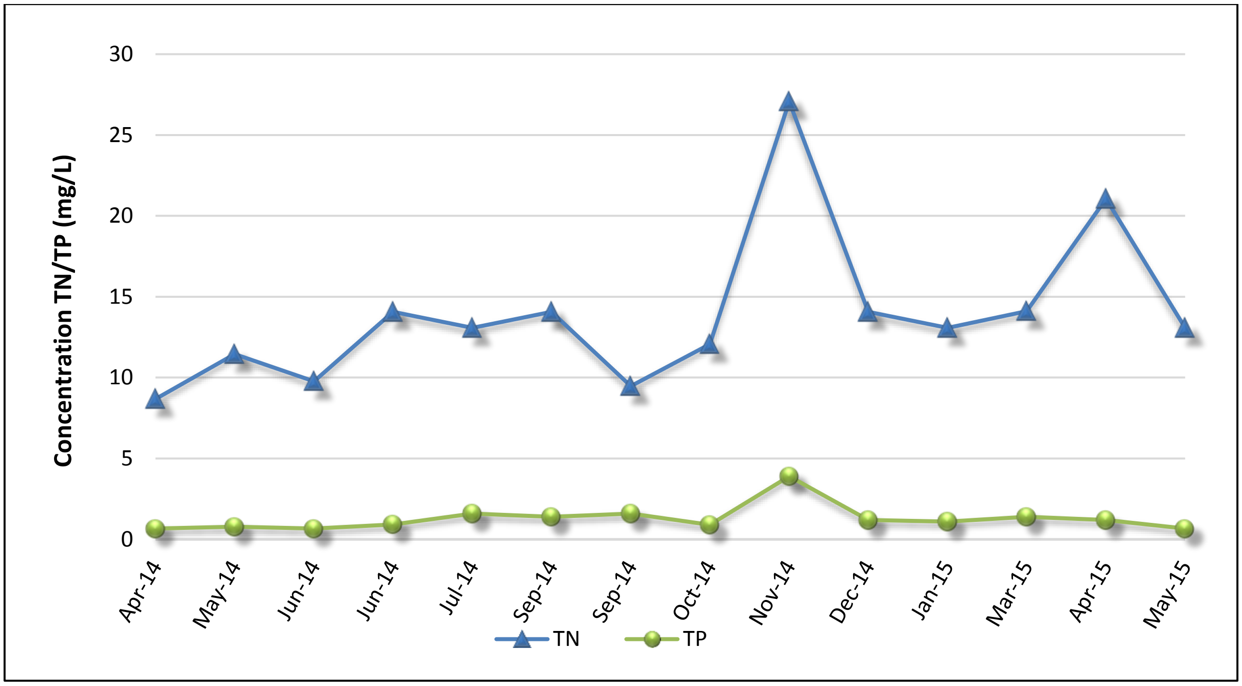

Figure 10 . *Concentrations of TN and TP in wastewater from Case Study 3, a residence equipped with a hybrid-urine-diversion toilet and composting toilet. Literature values (Lowe, K.S. et al.[4]) were assumed for pre-installation TN and TP.*

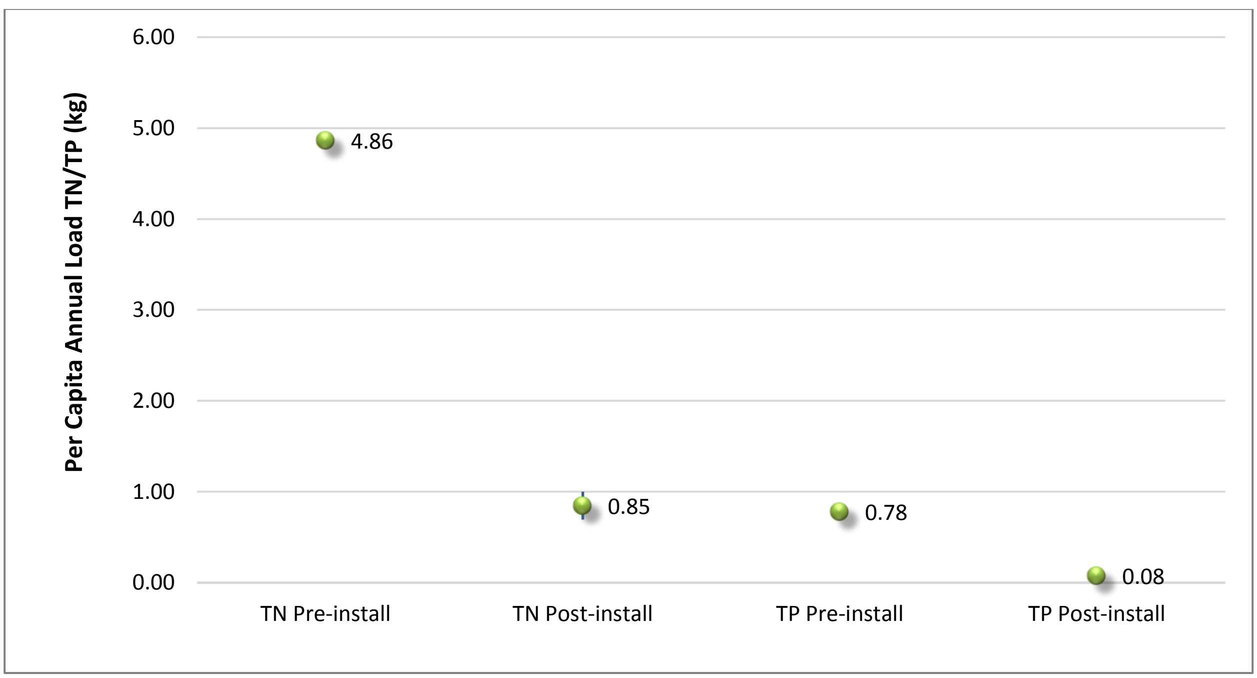

Figure 11. *Per capita TN and TP load reductions from Case Study 3, a residence equipped with a hybrid-urine-diversion toilet and composting toilet. A literature value (Lowe, K.S. et al.[4]) was assumed for pre-installation TN and TP and 14 post-installation samples were taken. Means and 95% confidence intervals are expressed for post installation TN and TP.*

Case Study 4: Home with Two Adult Occupants

Existing Onsite Wastewater Treatment

The existing system was comprised of a septic tank and soil absorption system.

Urine-diverting Toilet Installation

A urine-diverting toilet was installed for the only bathroom (figure 12). This offered a unique opportunity to isolate the efficacy of removing urine from wastewater for the management of nitrogen and phosphorus.

Sample Collection and Analysis

Samples were taken at the only accessible point in the "clear zone" of the septic tank using a polyethylene bailer. The mean concentration for two samples taken prior to the installation and use of urine diversion was calculated at 56.6 mg/L for TN (95% CI [45.7, 67.4]) and 5.6 mg/L for TP (95% CI [3.6, 7.6]). Thirteen post-installation samples were taken following a tank pump-out and re-fill. The mean concentration for post-installation samples was calculated at 34.0 mg/L for TN (95% CI [29.0, 39.0]) and 5.4 mg/L for TP (95% CI [4.8, 6.1]) (figure 13).

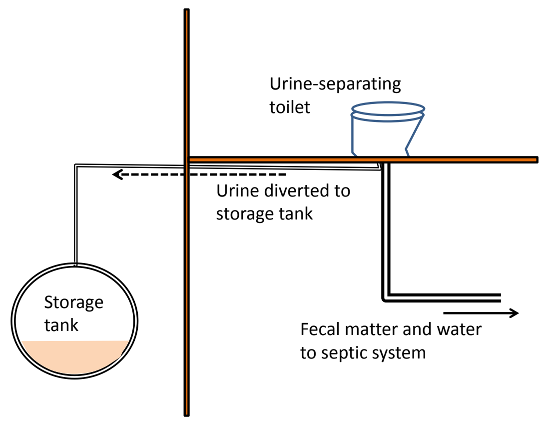

Figure 12. *Schemata of a urine diverting toilet installation.*

Outcome

Initial average TN and TP concentrations of 56.6 mg/L and 5.6 mg/L and average post-installation concentrations of 34.0 mg/L and 5.4 mg/L respectively were used for all calculations. This data indicates an approximate TN concentration reduction of 39.9% and an approximate TP concentration reduction of 3%. An examination of water usage indicates that this residence used 117 gal/day in the pre-installation period, resulting in a calculated nitrogen load of 4.6 kg/person/year (10.1 lbs/person/year) and a phosphorus load of 1.0 kg/person/year (2.2 lbs/person/year). Water use in 2014 following installation of the urine diverting toilet was decreased to 102 gal/day. Using this post-installation water usage and an average post-installation concentration of 34.0 mg/L TN and 5.4 mg/L TP, a nitrogen load reduction of approximately 47.5% to 2.4 kg/person/year (5.3 lbs/person/year) and a phosphorus load reduction of approximately 15% to 0.84 kg/person/year (1.6 lbs/person/year) was calculated for the property (figure 14).

Residuals

Urine volume was not tracked, therefore estimates of nitrogen loss to the urine or volatilization are not available.

Power Usage

Power usage is not necessary for this technology.

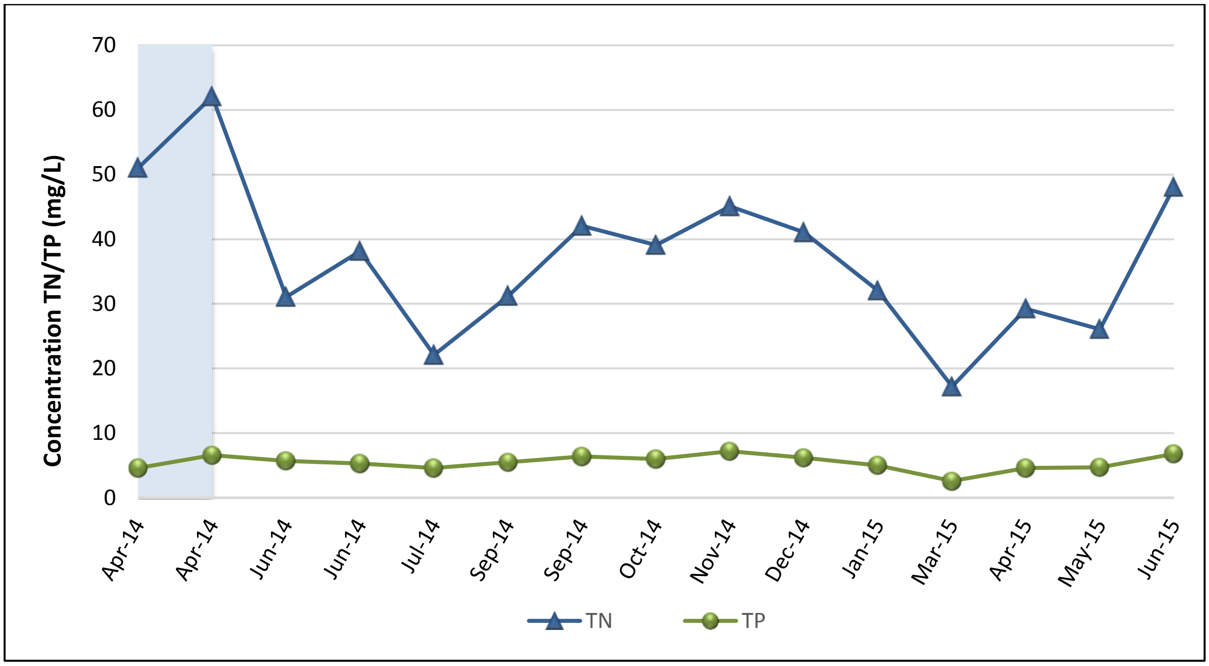

Figure 13. *Concentrations of TN and TP in wastewater from Case Study 4, a residence equipped with a urine-diverting toilet. The shaded area denotes concentrations prior to urine-diverting toilet installation and use.*

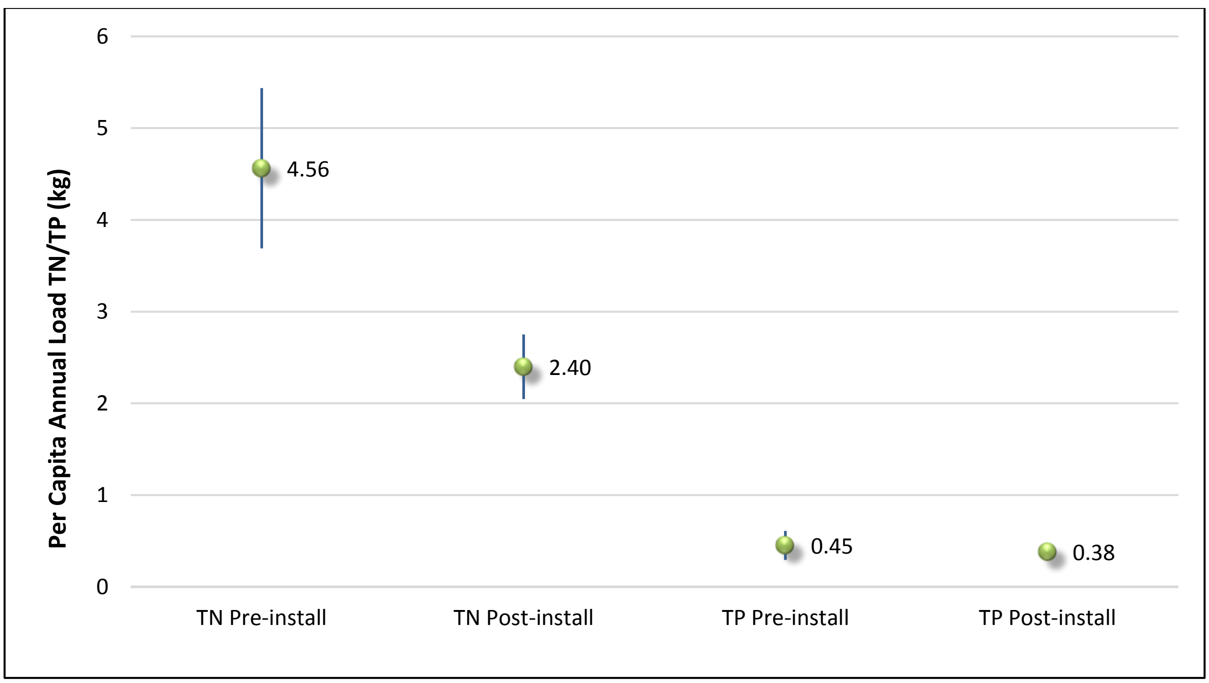

Figure 14. *Per capita TN and TP load reductions from Case Study 4, a residence equipped with a urine-diverting toilet. Two pre-installation and 13 post-installation samples were taken. Means and a 95% confidence interval are expressed for pre- and post-installation.*

<u>**Case Study 5 – Home with One Adult Occupant**</u>

Existing Onsite Wastewater Treatment

The existing septic system is comprised of a septic tank and soil absorption system.

Composting Toilet Installation

A Sun Mar self-contained composting toilet was installed (see figure 15).

Sample Collection and Analysis

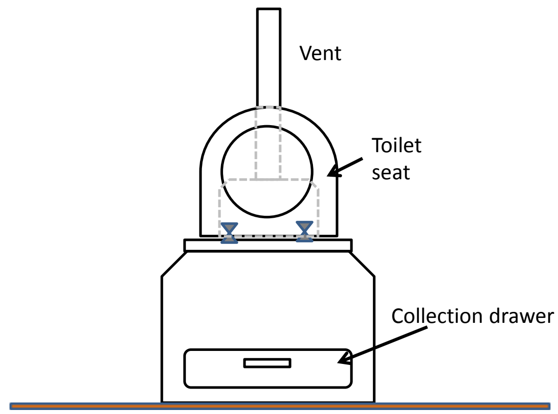

Figure 15. *Schemata of a self-contained composting toilet.*

Samples were taken at the only accessible point in the outlet tee (concrete baffle) of the septic tank using a polyethylene bailer. One sample was taken prior to installation and use of the composting toilet and showed TN and TP concentrations of 130 mg/L and 14 mg/L respectively. Fourteen post-installation samples were taken following a tank pump-out and re-fill. Four samples taken from July–October are discussed separately in these analyses and reflect a time when mechanical issues with the toilet went unresolved due to the occupant's need to provide care for a companion. The mean concentrations in remaining post-installation samples (excluding samples taken July–October 2014) were 13.5 mg/L for TN (95% CI [16.3, 10.6]) and 3.8 mg/L for TP (95% CI [7.1, 0.4]) (figure 16).

Outcome

Using initial TN and TP concentrations of 130 mg/L and 14 mg/L respectively, and comparing these with the ten post-installation values (excluding samples taken July–October 2014), the composting toilet yielded an approximate 89.6% TN concentration reduction to 13.5 mg/L and a 72.9% TP concentration reduction to 3.8 mg/L.

Prior to installation of the composting toilet, the nitrogen load was calculated at 13.3 kg/person/year (29.2 lbs/person/year) utilizing an average historic water usage of 74 gallons per day between 2011 and 2013. During 2014, the period when the majority of post-installation samples were taken, water usage was reduced by approximately 24% to 56 gallons per day. This calculates to an approximate nitrogen load reduction of 92% to 1.0 kg/person/year (2.3 lbs/person/year) and an approximate phosphorus load reduction of 80% to 0.3 kg/person/year (0.65 lbs/person/year). Again, these calculations do not include samples taken July–October 2014.

An analysis of all samples collected (even during times when the system was not fully operational), yields a comparable nitrogen load reduction to 1.7 kg/person/year (3.7 lbs/person/year) and a total phosphorus load reduction to 0.31 kg/person/year (0.69 lbs/person/year), which equates to nitrogen and phosphorus load reductions of approximately 87% and 78.2% respectively (figure 17).

***Author's Note**:* This installation was a self-contained composting toilet which required significantly more user attention than composting toilets with larger storage capacities.

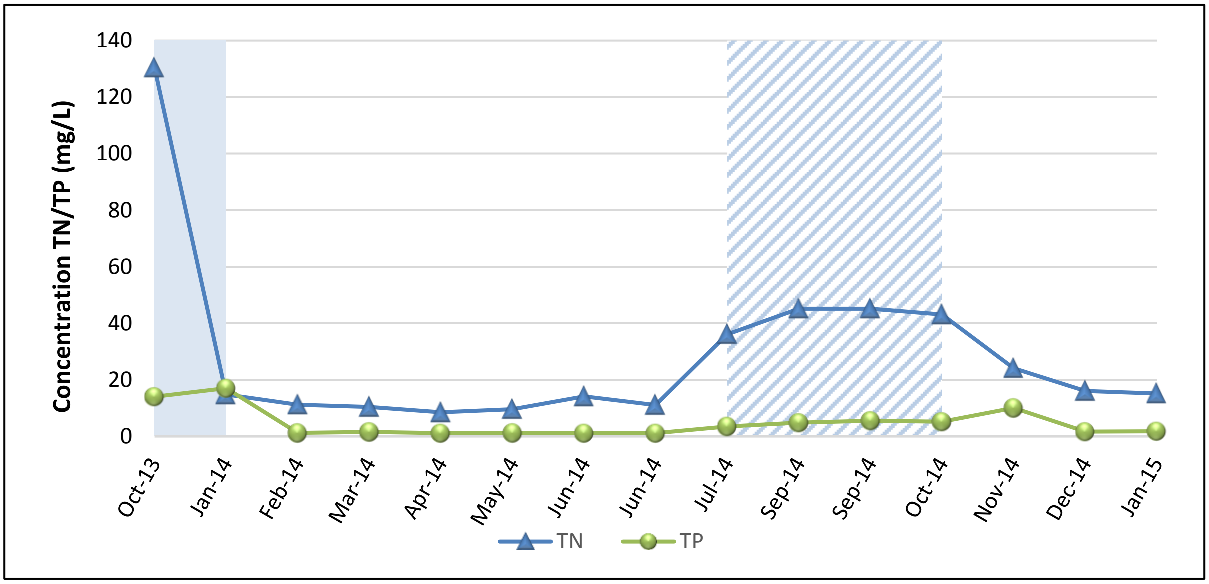

Figure 16. *Concentrations of TN and TP in wastewater from Case Study 5, a composting toilet-equipped residence. The shaded area denotes concentrations prior to compositing toilet installation and use. The diagonally striped area denotes a period of mechanical disrepair.*

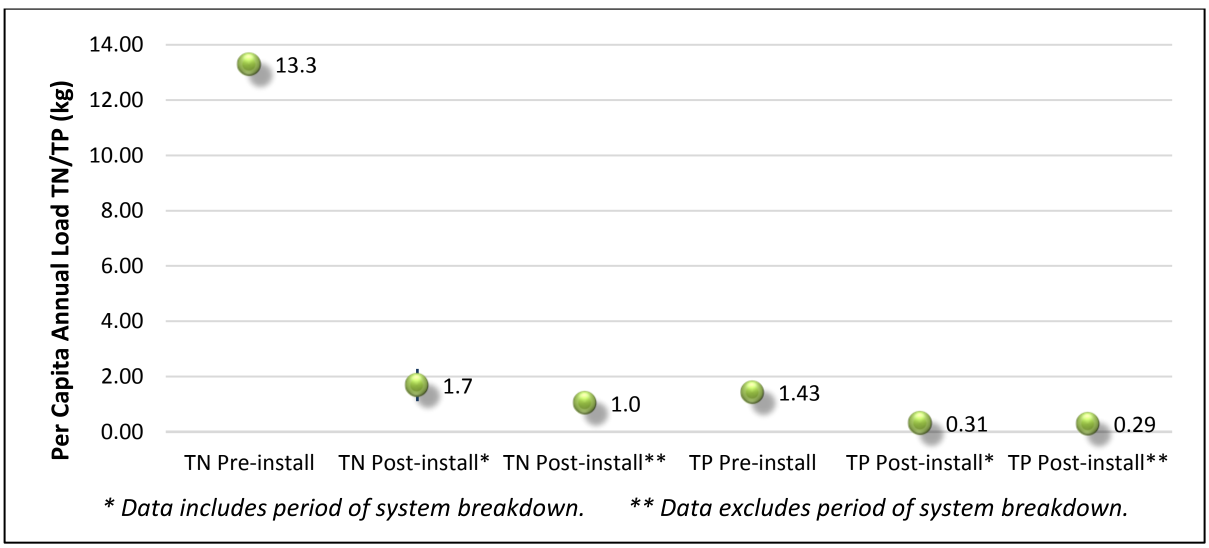

Figure 17. *Per capita TN and TP load reductions from Case Study 5, a composting toilet-equipped residence. One pre-installation sample and 14 post-installation samples were taken. Means and a 95% confidence interval are expressed for the post-installation period. Post-installation results are shown both with the system breakdown period (July–October 2014) included, as well as excluded from the data.*

Residuals

Analyses of residual solid compost or liquid compost were not conducted for this site.

Power Usage

No direct power usage readings were taken during 2014.

***

Case Study 6 – Home with Two Adult Occupants

Existing Onsite Wastewater Treatment

The existing septic system was comprised of a septic tank, distribution box and soil absorption system.

Composting Toilet Installation

The residents installed a Phoenix composting toilet using a standard "dry" toilet as well as a Dubbeletten urine diverting toilet. The Phoenix composting toilet was installed in the first-floor bathroom, which received the majority of use. The urine diversion toilet was installed in the second-floor guest bedroom, with liquid waste discharged into the composting bin and solid waste diverted to the septic tank (figure 18).

Sample Collection and Analysis

All samples were taken from the distribution box. Three pre-installation samples were taken that yielded a mean TN of 173.4 mg/L (95% CI [145, 202]) and a mean TP of 23.7 mg/L (95% CI [17, 30]). Since the highest values for TN and TP per Lowe, K.S. et al.[4] were 124 mg/L and 39.5 mg/L respectively, the pre-installation samples were used for the phosphorus reduction calculations, while the high value of 124 mg/L from Lowe, K.S. et al[4] was used for nitrogen calculations.

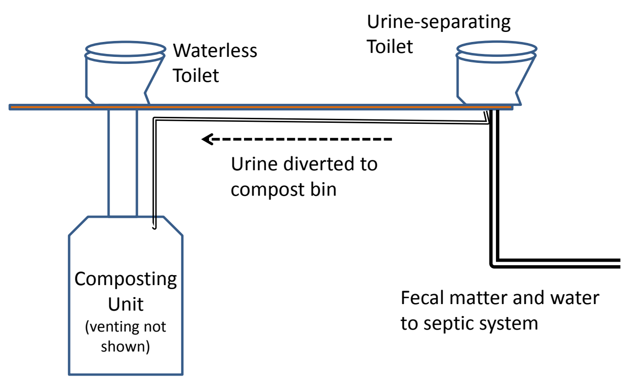

***Figure 18.** Schemata of a system incorporating a composing toilet and another toilet capable of conveying fecal matter to septic system.*

Of the 12 total post-installation samples, results were only considered for the ten samples that were taken after November 5, 2014, when the occupants reported that the septic tank reached full capacity after eco-toilet installation (figure 19).

Outcome

An initial mean TN concentration of 124 mg/L and a post-installation concentration of 39.6 mg/L indicates a TN concentration reduction of approximately 68%. An initial mean TP concentration of 23.7 mg/L and the post-installation TP concentration of 7.9 mg/L indicates a TP concentration reduction of approximately 67%. Water use remained low after installation with a pre-installation average of 37 gpd and a post-installation average of 26 gpd. Based on these numbers, TN output was reduced from 3.1 kg/person/year (6.9 lbs/person/year) to 0.7 kg/person/year (1.5 lbs/person/year) or approximately 78%. The TP output was reduced from 0.6 kg/person/year (1.3 lbs/person/year) to 0.14 kg/person/year (0.31 lbs/person/year) or approximately 77% (figure 20).

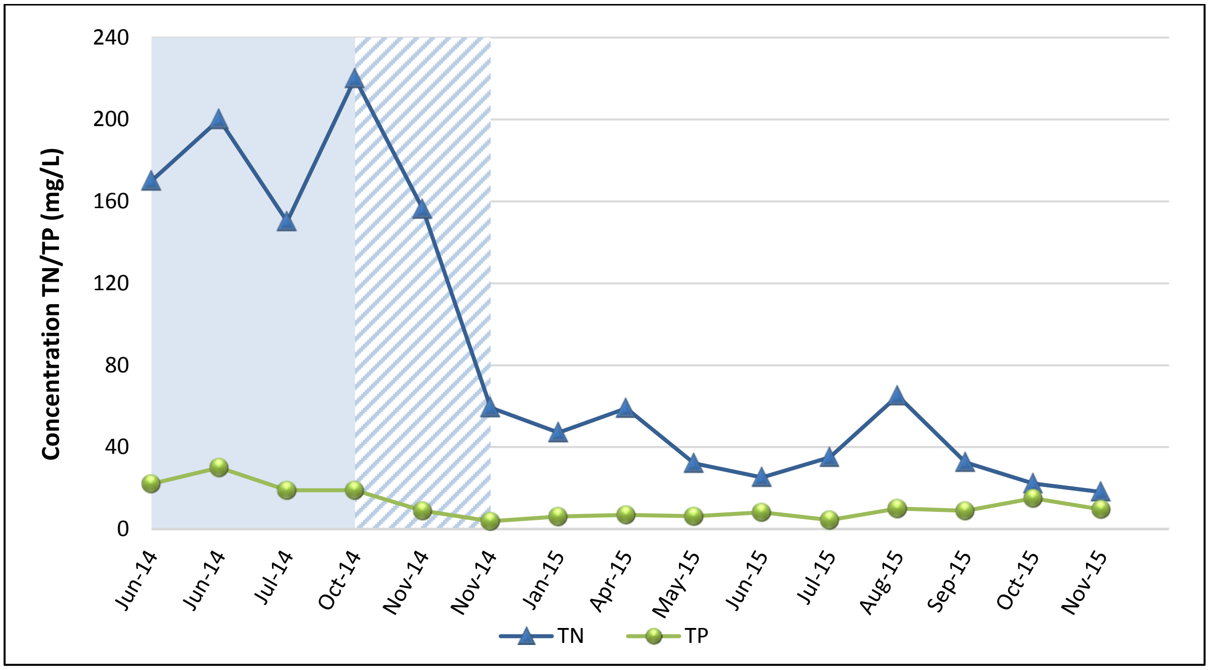

Figure 19. *Concentrations of TN and TP in wastewater from Case Study 6, a residence equipped with a hybrid-urine-diversion toilet and composting toilet. The shaded area denotes concentrations prior to installation and use. The diagonally striped area denotes area of uncertainty in data results, as the owner states the septic tank was not full until January 2015.*

Residuals

Per the owner, the composting toilet plus urine diverted from the lesser-used bathroom produced approximately 112 gallons of liquid "tea" in the twelve months monitored. Two samples of this tea were assayed for TN and TP and showed means of 1147 mg/L and 330 mg/L respectively. This volume translates to approximately 0.5 kg (1.1 lbs) of nitrogen and 0.14 kg (0.3 lbs) of phosphorus. Of the approximate 4.9 kg (10.7 lbs) of nitrogen removed from the home annually by the composting toilet, an approximate 10% was present in the compost "tea," with the remaining 90% either contained in the compost or lost to volatilization.

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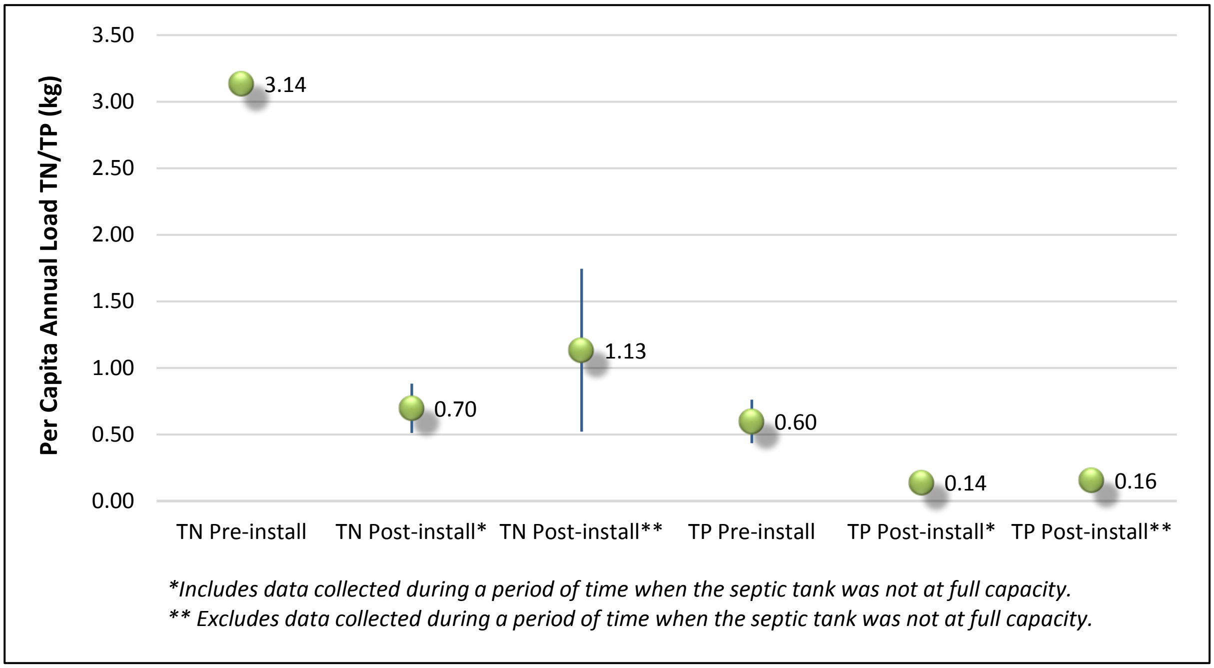

Figure 20. *Per capita TN and TP load reductions from Case Study 6, a residence equipped with a hybrid-urine-diversion toilet and composting toilet. Literature values (Lowe, K.S. et al.[4]) were assumed for pre-installation TN, and 15 post-installation samples were taken. Means and 95% confidence interval are expressed for post-installation TN and TP.*

***

<u>Case Study 7</u>: <u>Home with Two Adult Occupants</u>

Existing Onsite Wastewater Treatment

The existing system, built in 1982, consists of a septic tank and leach field which is now being used to dispose of graywater from the baths and kitchen facilities.

Composting Toilet Installation

In September of 2013, two vacuum-flush toilets were installed with liquid and solids being disposed of into a compost bin located in the garage area. Direct gravity compost units were not able to be utilized due to the existing building layout (figure 21).

Sample Collection and Analysis

Installation of the composting toilet was prior to the Falmouth Eco-toilet Project, therefore there are no pre-installation results available. Herein, as previously discussed, we use nominal pre-operation TN and TP concentrations of 64 mg/L and 10.3 mg/L respectively, based on a review of wastewater characteristics from residential septic tanks.[4]

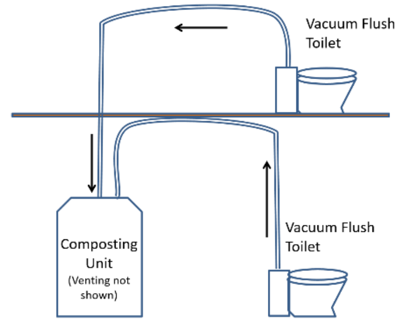

Figure 21. *Schemata of a composting toilet with two vacu-flush toilets.*

Following installation of the composting toilet, 11 samples were collected over the course of two years as the property is used seasonally. Samples show a mean concentration of 10.9 mg/L for TN [95% CI (13.7,8.1)] and 2.0 mg/L for TP [95% CI (2.5,1.5)]. Water use averaged approximately 36 gal/day/person prior to the installation of the composting toilet and was reduced by approximately 15% to 31 gal/day/person post-installation (figure 22).

Outcome

Utilizing the above-noted data, the estimated pre-installation nitrogen load of 3.2 kg/person/year (7.0 lbs/ person/year) was reduced by 86% to 0.5 kg/person/year (1.0 lbs/ person/year) and the phosphorus load was reduced by approximately 83% from a pre-installation mass of 0.51 kg/person/year (1.13 lbs/ person/year) to 0.08 kg/person/year (0.19 lbs/ person/year) (figure 23).

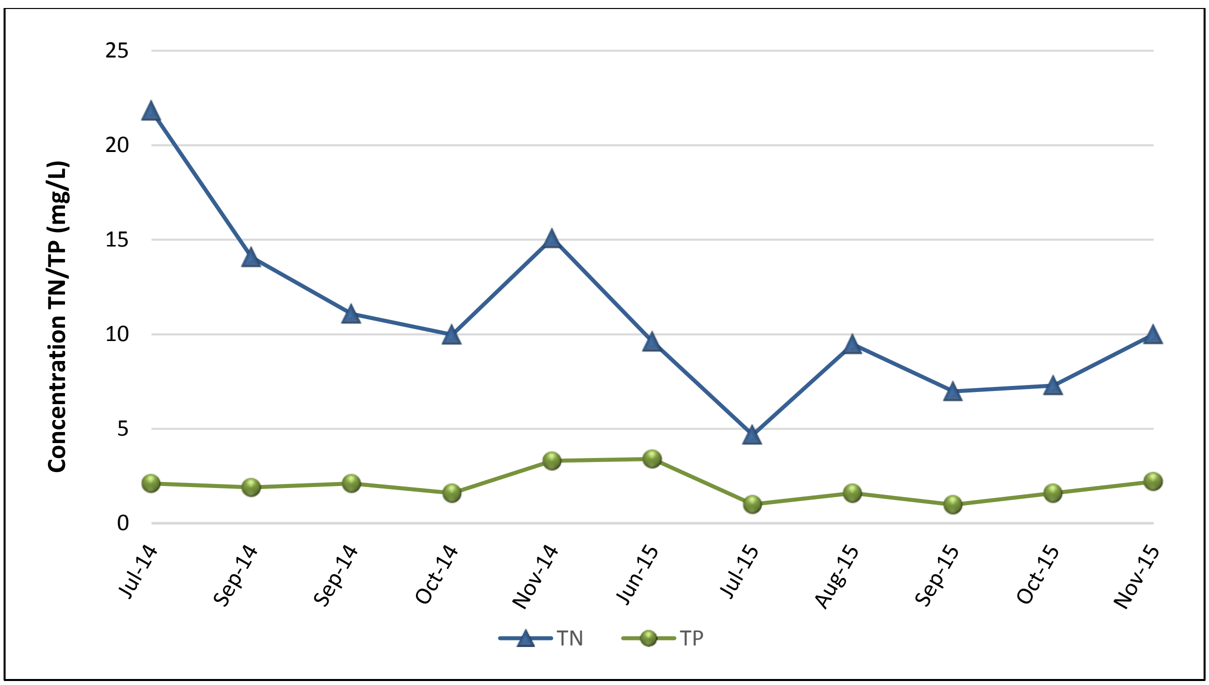

Figure 22. *Concentrations of TN and TP in wastewater from Case Study 7, a composting toilet-equipped residence. Literature values (Lowe, K.S. et al.[4]) were assumed for pre-installation TN and TP.*

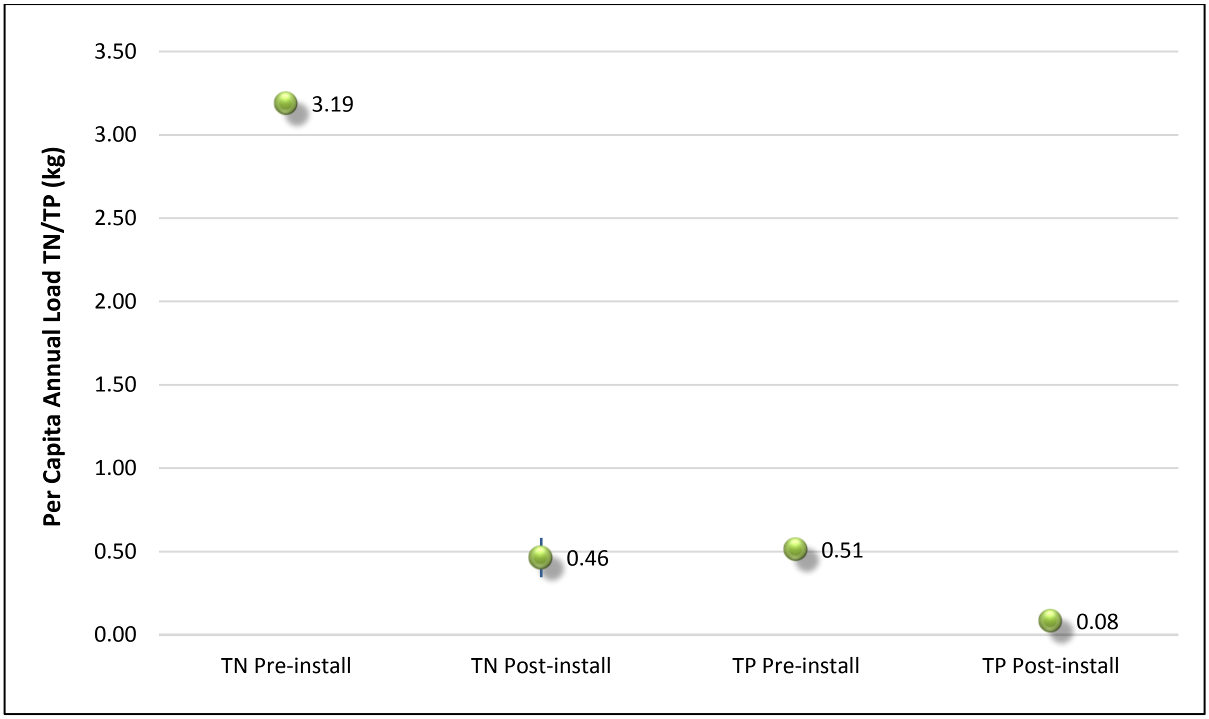

Figure 23. *Per capita TN and TP load reductions from Case Study 7, a composting toilet-equipped residence. Literature values (Lowe, K.S. et al.[4]) were assumed for pre-installation TN and TP, and 11 post-installation samples were taken. Means and a 95% confidence interval are expressed for post-installation.*

Residuals

The owners report ongoing adjustments to the operation of the eco-toilet components, citing an abundance of liquid discharge initially caused by vacuum-flush settings. Adjustments are still being made to the system and therefore there is no accurate leachate information.

Power Usage

Power usage was not specifically tracked for this system, however the owner/operators noted a significant increase in their electric bill after installation. Solar panels have since been installed to offset the cost.

***

Case Study 8: Home with Two Adult and Two Child Occupants

Existing Onsite Wastewater Treatment

The existing system consists of a single cesspool.

Urine-diverting Toilet Installation

A urine-diverting (UD) toilet was installed on October 11, 2014, for the residence's only bathroom (figure 24).

Sample Collection and Analysis

Samples were taken at the only accessible point in the "clear zone" of the cesspool using a polyethylene bailer. One sample was taken prior to installation and use of the urine diverting toilet and showed TN and TP concentrations of 15.1 mg/L and 7.6 mg/L, respectively. Twelve post-installation samples were taken following a cesspool pump-out and re-fill. The mean concentration for post-installation samples was 52.2 mg/L for TN [95% CI (60.1,44.3)] and 8.4 mg/L for TP [95%CI (9.3,7.4)] (figure 25).

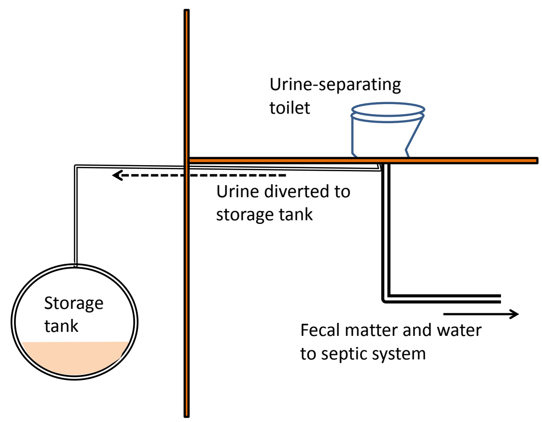

Figure 24. *Schemata of a urine-diverting toilet.*

Outcome

As the initial TN result was found to be lower than the average post-installation result for the UD toilet, a nominal value for TN concentration of 64.0 mg/L was used for this study based on the mean of all sites studied in Lowe, K.S. et al.[4], as discussed earlier. Using an initial concentration of 64.0 mg/L and an average post-installation concentration of 52.2 mg/L, the results indicate an approximate TN concentration reduction of 18%. An examination of water use indicated that this residence used 144 gal/day in the pre-installation period, resulting in a nitrogen load of 3.2 kg/person/year (7 lbs/person/year). Water use in 2014, following installation of the urine diverting toilet, was decreased to 92 gal/day which reduced the residence's nitrogen load by 48% to 1.7 kg/person/year (3.7 lbs/person/year). Per capita phosphorus load was reduced by approximately 30% from an initial load of 0.4 kg/person/year (0.8 lbs/person/year) to 0.3 kg/person/year (0.6 lbs/person/year) (figure 26).

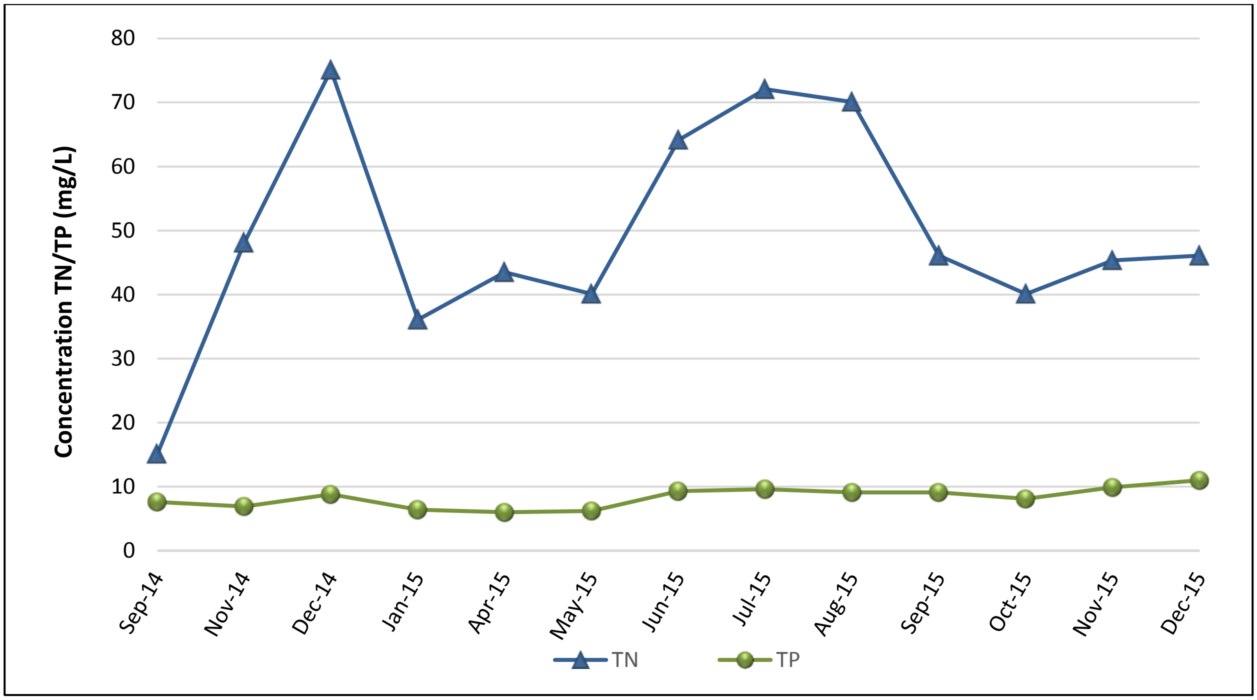

Figure 25. *Concentrations of TN and TP in wastewater from Case Study 8, a residence equipped with a urine-diverting toilet. Literature values (Lowe, K.S. et al.[4]) were assumed for pre-installation TN.*

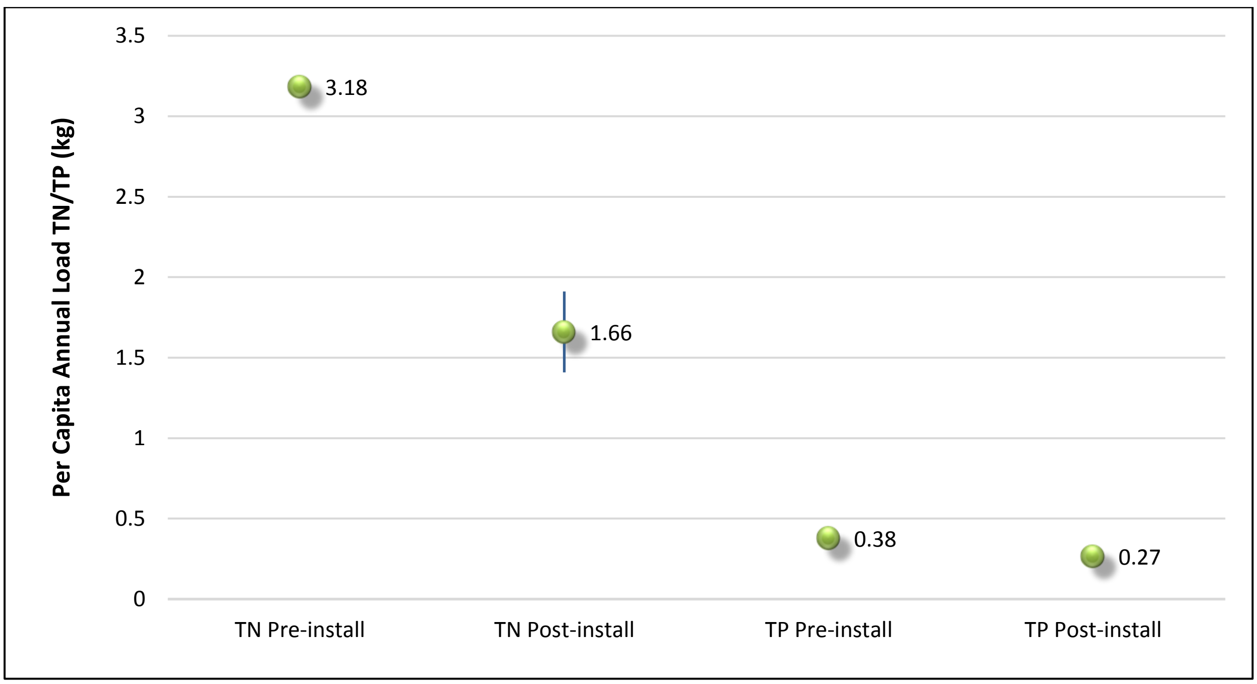

Figure 26. *Per capita TN and TP load reductions from Case Study 8, a residence equipped with a urine-diverting toilet. Literature values (Lowe, K.S. et al.[4]) were assumed for pre-installation TN, and 12 post-installation samples were taken. Means and a 95% confidence interval are expressed for pre- and post- installation.*

Residuals

As of the writing of this report, no urine has been removed from the storage tank. Therefore, estimates of nitrogen loss to the urine or volatilization are not available.

Power Usage

Power usage is not necessary for this technology.

***

Case Study 9: Home with Two Adult and Two Child Occupants

Existing Onsite Wastewater Treatment

Composting toilets at this site were installed approximately 14 years prior to the current study.

Composting Toilet Installation

A Phoenix composting toilet (four-person unit) was installed with two “dry” toilets situated above the bin (one on the first floor and one on the second floor) (figure 27).

Sample Collection and Analysis

This residence has a total of four occupants; two adult occupants and two children under the age of ten. No information was collected regarding the pre-existing septic system, nor was pre-existing sampling conducted at the location. Instead, pre-installation average concentration readings of 64 mg/L TN and 10.3 mg/L TP, from Lowe, K.S. et al.[4] were assumed for all calculations. A nominal 20% reduction in water usage was also assumed as discussed previously (figure 28).

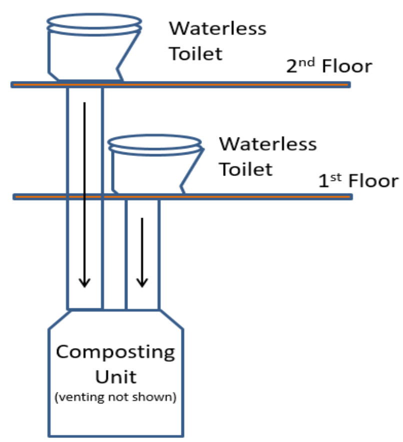

***Figure 27**. Schemata of a composting toilet with two waterless toilets situated above the composting unit.*

Outcome

Twelve post-installation samples were collected over the course of one year resulting in a mean TN concentration TN of 18.3 mg/L (95% CI [14.2, 22.5]) and 4.5 mg/L TP (95% CI [2.0, 7.0]).

Using an initial TN concentration of 64 mg/L and an initial TP concentration of 10.3 mg/L, plus post-installation average TN and TP concentration of 18.3 mg/L and 4.5 mg/L respectively, we can therefore calculate TN and TP concentration reductions of 71% and 56% respectively.

Utilizing the above noted data, the pre-installation nitrogen load calculated at 4.9 kg/person/year (10.7 lbs/person/year), was reduced by approximately 77% to 1.1 kg/person/year (2.5 lbs/person/year). The phosphorus load was reduced by almost 65% from a pre-installation mass of .08 kg/person/year (1.7 lbs/person/year) to 0.3 kg/person/year (0.6 lbs/person/year) (figure 29).

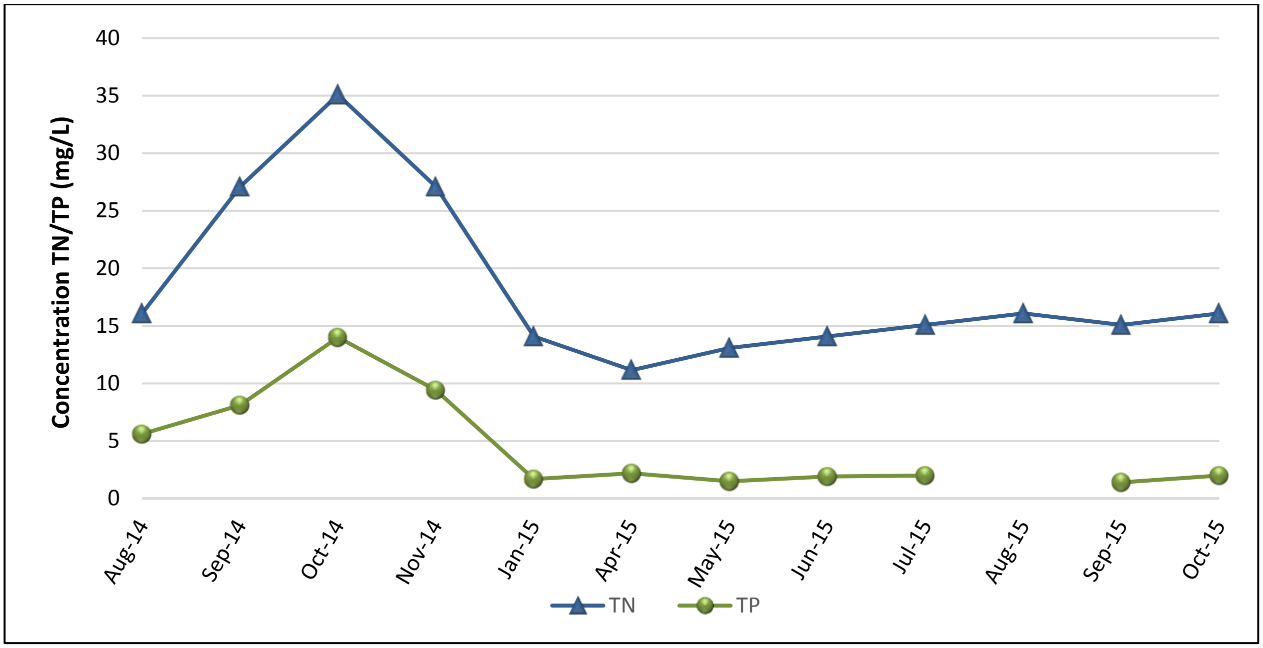

Figure 28. *Concentrations of TN and TP in wastewater from Case Study 9, a composting-toilet equipped residence. Literature values (Lowe, K.S. et al.[4]) were assumed for pre-installation TN and TP values. Due to a sampling error, no TP results are shown for August 2015.*

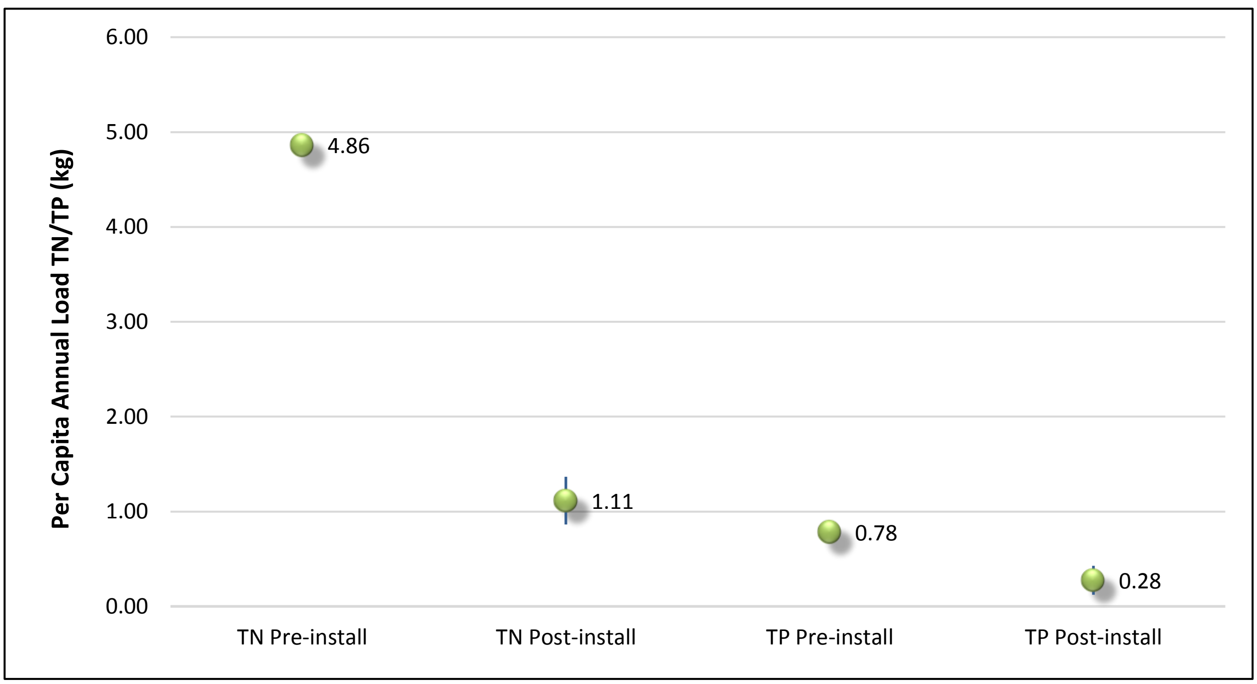

Figure 29. *Per capita TN and TP load reductions from Case Study 9, a composting toilet-equipped residence. Literature values (Lowe, K.S. et al.[4]) were assumed for pre-installation TN and TP values, and 12 post-installation samples were taken. Means and a 95% confidence interval are expressed for post-installation.*

Residuals

The composting toilet produced approximately 165 gallons of liquid “tea” in a six-month period. A single sample of the tea was assayed for TN and TP with results of 1719 mg/L and 550 mg/L respectively. Using a total of 330 gallons of liquid per year, this volume translates to approximately 2.15 kg (4.73 lbs) of nitrogen. Of the 15.0 kg (33.1 lbs) of nitrogen removed by the composting toilet, 14% was present in the compost “tea,” with the remaining 86% either contained in the compost or lost to volatilization.

Power Usage

No direct power usage readings were taken at this site.

***

Case Study 10: Home Occupied Initially by Two Adults with Two Adults Added

Existing Onsite Wastewater Treatment

The existing system consists of a tank and cesspool components.

Urine-diverting Toilet Installation

Urine-diverting (UD) toilets were installed in May of 2014 for the three existing bathrooms in the dwelling (figure 30). Per the owner, prior to installation and use of the urine diverting toilets there were two occupants in the dwelling. Shortly after the UD toilets were installed, two additional occupants moved into the dwelling.

Sample Collection and Analysis

Samples were taken at the only accessible point in the “clear zone” of the existing cesspool using a polyethylene bailer. No samples were taken prior to installation and use of the urine-diverting toilets. Twelve post-installation samples were taken showing high results for both TN and TP. The mean concentration was 398 mg/L for TN (95% CI [685, 112]) and 119 mg/L for TP (95% CI [235, 4.0]) (figure 31).

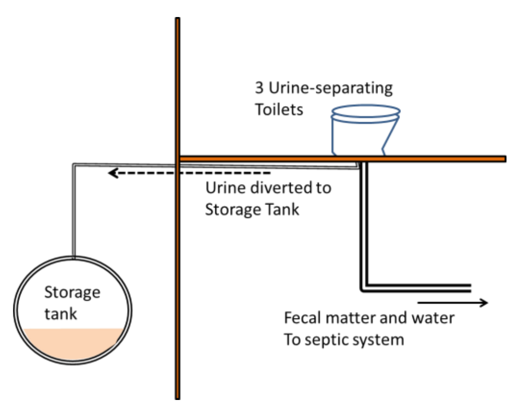

Figure 30. *Schemata of 3 urine separating toilets.*

Outcome

Pre-installation water readings show a maximum average of 10 gpd household water usage and a post-installation water usage average of approximately 60 gpd. These reading are inconsistent with results from similar cases in this study. Additionally, no pre-installation samples were taken at this site and post-installation data for TN and TP concentrations are very erratic (figure 31). Due to these factors, we have eliminated Case Study 10 from the statistical analysis.

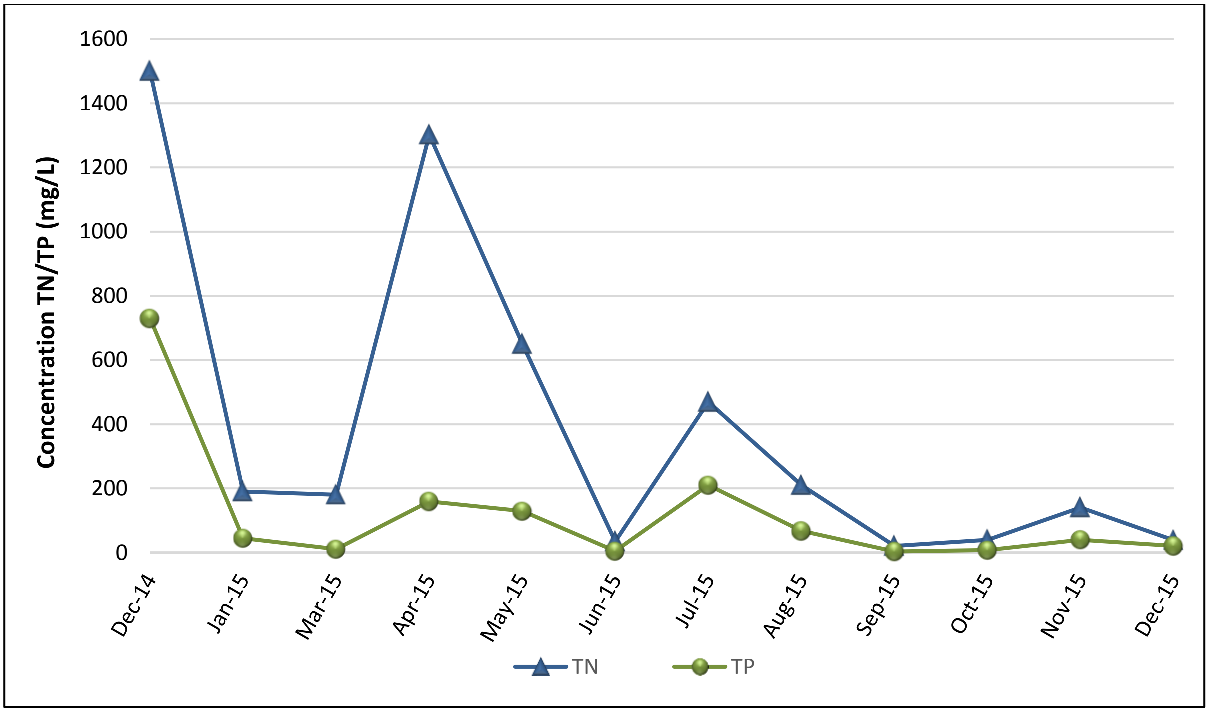

Figure 31. *Concentrations of TN and TP in wastewater from Case Study 10, a residence equipped with urine-diverting toilets. Literature values (Lowe, K.S. et al.[4]) were assumed for pre-installation TN and TP.*

Residuals

As of the writing of this report, the homeowner estimates that the urine tank needs to be pumped every six or seven months. The tank size is 150 gallons and at last pumping the cost was $100.

Power Usage

Power usage is not necessary for this technology.

***

Case Study 11: Home with Two Adult Occupants

Existing Onsite Wastewater Treatment

Details regarding the pre-existing septic system are unknown and no pre-installation samples were taken.

Composting Toilet Installation

The residents installed a hybrid urine-diversion seat and composting toilet in June 2014. Due to the design, only graywater, no urine or feces, was discharged into system (figure 32).

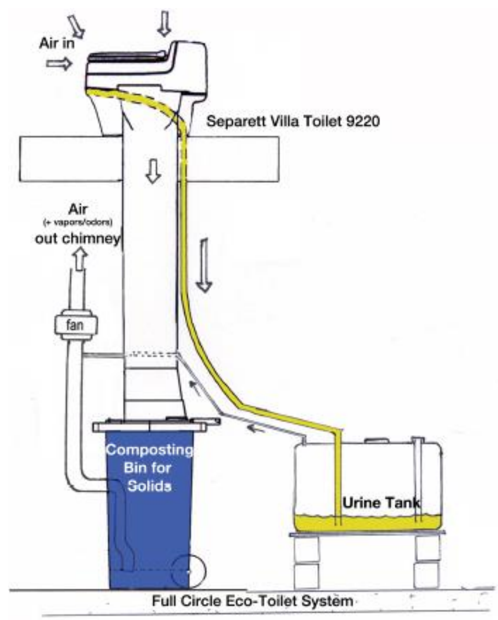

Figure 32*. Schemata of a hybrid urine-diversion/composting toilet.*

Sample Collection and Analysis

All 12 samples were taken from the distribution box. Of these 12 samples, only the last 8 are considered in this discussion as the first 4 samples were unusually high, possibly due to loose cover over the distribution box. Also, since installation of eco-toilet technology pre-dates the program, mean TN and TP concentrations were assumed based on Lowe, K.S. et al.[4] as previously discussed (figure 33).

Outcome

An initial mean TN concentration of 64 mg/L and a post-installation concentration of 8.1 mg/L indicated a TN concentration reduction of approximately 87%. The initial mean TP concentration of 10.3 mg/L and the post-installation TP concentration of 1.38 mg/L indicates a TP concentration reduction of approximately 87%. Additionally, there were no pre- and post-installation water readings taken, therefore, a conservative 20% water use reduction was assumed as previously discussed. Utilizing the above noted data, the pre-installation nitrogen load of 4.9 kg/person/year (10.7 lbs/person/year) was reduced by 90% to 0.49 kg/person/year (0.5 lbs/ person/year) and the phosphorus load was reduced by 89% from a pre-installation mass of 0.78 kg/person/year (1.73 lbs/person/year) to 0.08 kg/person/year (0.18 lbs/ person/year) (figure 34).

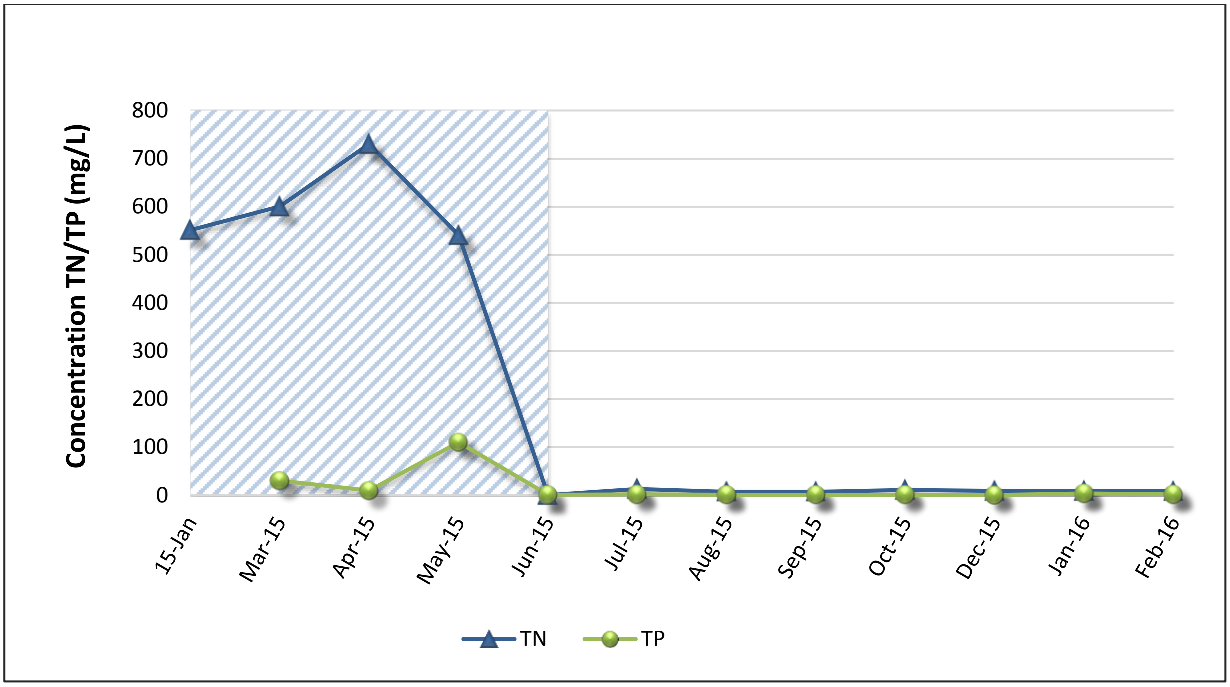

Figure 33. *Concentrations of TN and TP in wastewater from Case Study 11, a residence equipped with a hybrid urine-diversion seat and composting toilet. The diagonally striped area denotes abnormally high sampling results that have been discounted for discussion purposes. Literature values (Lowe, K.S. et al.[4]) were assumed for pre-installation TN and TP.*

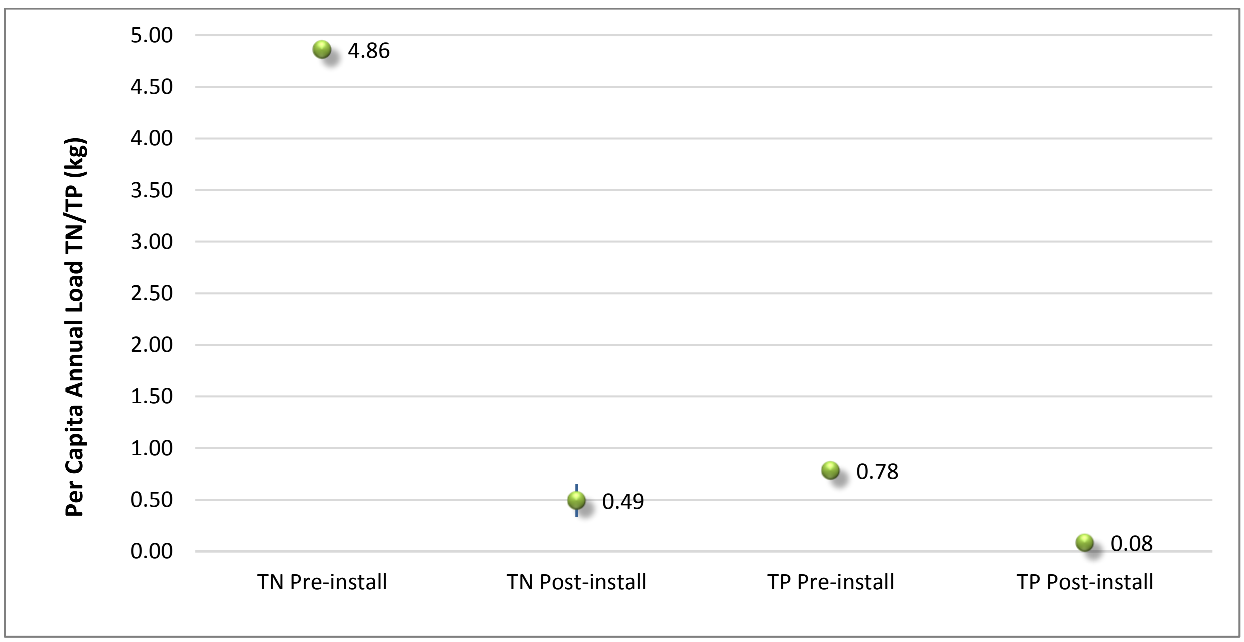

Figure 34. *Per capita TN and TP load reductions from Case Study 11, a residence equipped with a hybrid-urine-diversion seat and composting toilet. Literature values (Lowe, K.S. et al.[4]) were assumed for pre-installation values and 11 post-installation TN and TP samples were taken. Results shown for samples collected after May 2015 as previous samples show unusually high results. Means and a 95% confidence interval are expressed for post-installation TN and TP.*

Composting Toilets – Summary of Results

Case Studies 2 and 9 represent the most typical composting toilet models that use gravity to deposit toilet waste into a container located a building level below the toilet. Case Studies 1 and 7 consisted of typical composting units and additionally, at these two locations, low-volume vacuum flush toilets were employed to serve toilets located in areas of the home unable to discharge by gravity alone. Case Study 5 consisted of a self-contained unit, where the storage and processing bin is located directly under the commode. This dwelling was occupied by a single resident.

As noted previously, assumptions were made in situations where there were no pre-installation samples available or where water usage records were considered questionable. In Case Studies 7 and 9, both toilet installations pre-date the start of this study and hence an initial concentration of 64 mg/L TN was assumed at these sites based on the mean value of all sites from Lowe, K.S. et al.[4] In Case Study 2, the two initial samples showed TN concentrations of 630 mg/L and 340 mg/L respectively. Since these samples were taken at the outlet of the septic tank that had been pumped, but not completely cleaned, the values are considered biased. Based on these high sample values, an initial concentration of 124 mg/L TN was used based on the maximum of all values from Lowe, K.S. et al.[4]

Water use readings were also assumed for Case Studies 2 and 9. Case Study 2 produced erratic readings over the period of the study and the installation for Case Study 9 pre-dates this program. A water use reduction of 20% was assumed and a pre-installation value of 55 gpd was utilized for both properties as discussed previously.

For Case Study 5, four samples taken from July–October are discussed separately in these analyses and reflect a time when mechanical issues with the toilet went unresolved due to the occupant's need to provide care for a companion.

Nitrogen data for composting toilets are presented in table 2.

Case study #	Pre Install N conc. mg/L	Post Install N conc. mg/L	Pre install N load (lb per person)	Pre install N load (kg per person)	Post install N load (lb per person)	Post install N load (kg per person)	% N Load reduction
1	**54.6**	**7.6**	**6.14**	**2.78**	**0.55**	**0.25**	**91.0%**
2*	**124**	**23.9**	**20.77**	**9.42**	**3.20**	**1.45**	**84.6%**
5A	**130**	**21.7**	**29.22**	**13.26**	**3.73**	**1.69**	**92.1%**
5B	**130**	**13.5**	**29.22**	**13.26**	**2.30**	**1.04**	**87.2%**
7	**64**	**10.9**	**7.03**	**3.19**	**1.02**	**0.46**	**85.5%**
9*	**64**	**18.3**	**10.72**	**4.86**	**2.46**	**1.11**	**77.1%**
mean	**94.4**	**16.0**	**17.18**	**7.79**	**2.21**	**1.00**	**86.3%**
median	**94.0**	**15.9**	**15.75**	**7.14**	**2.38**	**1.08**	**86.3%**
max	**130.0**	**23.9**	**29.22**	**13.26**	**3.73**	**1.69**	**92.1%**
min	**54.6**	**7.6**	**6.14**	**2.78**	**0.55**	**0.25**	**77.1%**

Table 2. *Nitrogen data for composting toilet case studies. Loads are calculated per year. Dataset 5A includes all samples from July–October; dataset 5B removes those data points from the calculations. *Water usage assumed for calculations. Underline denotes assumed initial concentration based on Lowe, K.S. et al.*[4]

With regards to phosphorus, an initial TP concentration of 10.3 mg/L was assumed for Case Studies 7 and 9 based on the mean value of all sites from Lowe, K.S. et al.[4] In Case Study 2, two initial TP samples also showed abnormal values of 27 mg/L and 42 mg/L. Since these values approximated the highest values observed by Lowe, K.S et al.[4] their average was used to calculate load reduction. Phosphorus data for composting toilets are presented in table 3.

Case study #	Pre Install P conc. mg/L	Post Install P conc. mg/L	Pre install P load (lb per person)	Pre install P load (kg per person)	Post install P load (lb per person)	Post install P load (kg per person)	P load reduction %
1	**6.9**	**0.9**	**0.78**	**0.35**	**0.06**	**0.03**	**91.9%**
2*	**34.5**	**2.4**	**5.78**	**2.62**	**0.32**	**0.15**	**94.5%**
5A	**14.0**	**4.0**	**3.15**	**1.43**	**0.69**	**0.31**	**78.2%**
5B	**14.0**	**3.8**	**3.15**	**1.43**	**0.65**	**0.29**	**79.4%**
7	**10.3**	**2.0**	**1.13**	**0.51**	**0.19**	**0.08**	**83.4%**
9*	**10.3**	**4.5**	**1.73**	**0.78**	**0.61**	**0.28**	**64.8%**
mean	**15.0**	**2.9**	**2.62**	**1.19**	**0.42**	**0.19**	**82.0%**
median	**12.2**	**3.1**	**2.44**	**1.11**	**0.46**	**0.21**	**81.4%**
max	**34.5**	**4.5**	**5.78**	**2.62**	**0.69**	**0.31**	**94.5%**
min	**6.9**	**0.9**	**0.78**	**0.35**	**0.06**	**0.03**	**64.8%**

Table 3. *Phosphorus data for composting toilet case studies. Loads are calculated per year. Dataset 5A includes all samples from July–October; dataset 5B removes those data points from the calculations. *Water usage assumed for calculations. Underline denotes assumed initial concentration based on Lowe, K.S. et al.[4]*

Urine Diversion (UD) Toilets – Summary of Results

Case Studies 4, 8 and 10 only varied from traditional wastewater disposal by the diversion of urine from the main waste stream into an external tight tank for later removal. Case Study 4 served two adult occupants while Case Study 8 served two adults and two children. In Case Study 10, the occupancy increased from two to four adults part-way through the study.

One pre-installation sample was taken for Case Study 8 with an abnormally low TN result of 15.1 mg/L. For this property, the mean TN value of 64 mg/L for all locations studied in Lowe, K.S. et al.[4] was assumed.

Case Study 10 was eliminated from the statistical analysis due to the inconsistent nature of results. There were no pre-installation samples taken for Case Study 10 and water meter readings were erratic, showing average pre-installation values ranging from 92 gpd in 2012 and 10 gpd in 2013, to post-installation averages of 27 gpd in 2014 and 148 gpd in 2015. Twelve post-installation TN and TP sampling results were similarly inconsistent. Total Nitrogen ranged from a maximum of 1500 mg/L to a minimum of 20.8 mg/L with an average of 398.1 mg/L, while TP ranged from a maximum of 730.0 mg/L to a minimum of 3.5 mg/L with an average of 119.3 mg/L.

Nitrogen data for UD toilets are presented in table 4.

Case study #	Pre Install N conc. mg/L	Post Install N conc. mg/L	Pre install N load (lb per person)	Pre install N load (kg per person)	Post install N load (lb per person)	Post install N load (kg per person)	% N Load reduction
4	56.6	34.0	10.06	4.56	5.28	2.40	47.5%
8	64.0	52.2	7.02	3.18	3.66	1.66	47.9%
~~10*~~	~~124.0~~	~~398.0~~	~~20.77~~	~~9.42~~	~~53.34~~	~~24.20~~	~~-156.8%~~
mean	60.3	43.1	8.54	3.87	4.47	2.03	47.7%
median	60.3	43.1	8.54	3.87	4.47	2.03	47.7%
max	64.0	52.2	10.06	4.56	5.28	2.40	47.9%
min	56.6	34.0	7.02	3.18	3.66	1.66	47.5%

Table 4. *Nitrogen data for urine diverting toilet case studies. Loads are calculated per year. *Water usage assumed for calculations. Underline denotes assumed initial concentration based on Lowe, K.S. et al[4].*

Phosphorus data for UD toilets are presented in table 5.

Case study #	Pre Install P conc. mg/L	Post Install P conc. mg/L	Pre install P load (lb per person)	Pre install P load (kg per person)	Post install P load (lb per person)	Post install P load (kg per person)	P load reduction %
4	5.6	5.4	1.00	0.45	0.84	0.38	15.3%
8	7.6	8.4	0.83	0.38	0.59	0.27	29.6%
~~10*~~	~~39.5~~	~~119.0~~	~~6.70~~	~~3.04~~	~~15.95~~	~~7.23~~	~~-138.0%~~
mean	6.6	6.9	0.91	0.41	0.71	0.32	22.5%
median	6.6	6.9	0.91	0.41	0.71	0.32	22.5%
max	7.6	8.4	1.00	0.45	0.84	0.38	29.6%
min	5.6	5.4	0.83	0.38	0.59	0.27	15.3%

Table 5. *Phosphorus data for urine diverting toilet case studies. Loads are calculated per year. *Water usage assumed for calculations. Underline denotes assumed initial concentration based on Lowe, K.S. et al[4].*

Multiple Technologies – Summary of Results

Three of the properties in the study utilized a combination of composting and urine diversion technologies. Case Studies 3 and 6 both employed urine diversion technology to serve toilet facilities located such that they could not utilize gravity for the combined fecal/urine toilet discharge. In both cases, fecal material was discharged into the existing septic system. It is important to note that both owners report that these units received only limited use.

All three case studies that utilized multiple technologies assume pre-installation values that are based on Lowe, K.S. et al.[4] For instance, Case Studies 3 and 11 utilize the mean TN value of all sites reviewed (64 mg/L), since pre-installation samples were not obtained from either property. Pre-installation samples from Case Study 6 demonstrated high TN concentrations of 170 mg/L, 200 mg/L and 150 mg/L. In the interest of more accurately estimating nitrogen load, a TN concentration of 124 mg/L (the highest of values found in Lowe, K.S. et al.[4]) was used for calculations.

Case Study 11 showed an overall nitrogen load reduction of 90%, after discounting abnormally high Total N values for the first four samples (551, 600, 730 and 541 mg/L respectively). The fifth sample dropped to 0.11 mg/L TN, but leveled out for the remaining seven samples averaging 8.1 mg/L TN with a maximum of 13.1 mg/L TN and a minimum of 7.1 mg/L TN. According to the owners, all human waste was collected and used for fertilizer or buried, and 99% of their food waste was fed to their chickens. There was also no laundry discharge into the system.

Case Study 6 is broken into two timeframes based on reporting from the owners that the septic tank was pumped out on September 17, 2014, after installation of the eco-toilet technology. The owners also reported that the septic tank was not refilled until after the November 5, 2014 sampling date. For reporting purposes, tables 6 and 7 illustrate values based on two data sets. Data set 6A includes only data collected from November 19, 2014 inclusively, through the end of the trial. Data set 6B includes all data collected after the installation of the eco-toilet components, which includes sampling conducted in October of 2014 and November 5, 2014 through the end of the trial. Samples taken on October 15 and November 5, 2014 show TN results of 220 mg/L and 156 mg/L respectively. After the November 5, 2014 sample was taken, the results reduce to a maximum of 65 mg/L and a minimum of 22 mg/L for TN, indicating system equilibrium was likely reached during this timeframe. Nitrogen data for case studies where both urine diversion and composting technologies were used are presented in table 6.

Case study #	Pre Install N conc. mg/L	Post Install N conc. mg/L	Pre install N load (lb per person)	Pre install N load (kg per person)	Post install N load (lb per person)	Post install N load (kg per person)	% N Load reduction
3*	64.0	13.9	10.72	4.86	1.87	0.85	82.6%
6A	124.0	39.6	6.91	3.14	1.54	0.70	77.7%
6B	124.0	64.3	6.91	3.14	2.50	1.13	63.9%
11*	64.0	8.1	10.72	4.86	1.09	0.49	89.9%
mean	94.0	31.5	8.82	4.00	1.75	0.79	78.5%
median	94.0	26.8	8.82	4.00	1.70	0.77	80.2%
max	124.0	64.3	10.72	4.86	2.50	1.13	89.9%
min	64.0	8.1	6.91	3.14	1.09	0.49	63.9%

Table 6. *Nitrogen data for case studies where both urine diversion and composting technologies were used. Loads are calculated per year. *Water usage assumed for calculations. Underline denotes assumed initial concentration based on Lowe, K.S. et al.*[4] Dataset 6A includes only samples taken after occupants reported septic tank had reached full capacity; dataset 6B includes all post-installation samples.

As noted above, there are no pre-installation samples for either Case Study 3 or Case Study 11. In these cases, the mean of all samples reviewed in Lowe, K.S. et al.[4], 10.3 mg/L, was assumed for pre-installation TP concentration. For Case Study 6, the pre-installation results of 22 mg/L, 30 mg/L and 19 mg/L TP all fell below the maximum literature value[4] of 39.5 mg/L; therefore, the pre-installation average was used.

Phosphorus data for case studies where both urine diversion and composting technologies were used are presented in table 7.

Case study #	Pre Install P conc. mg/L	Post Install P conc. mg/L	Pre install P load (lb per person)	Pre install P load (kg per person)	Post install P load (lb per person)	Post install P load (kg per person)	P load reduction %
3*	10.3	1.29	1.73	0.78	0.17	0.08	90.0%
6A	23.7	7.90	1.32	0.60	0.31	0.14	76.8%
6B	23.7	8.90	1.32	0.60	0.35	0.16	73.8%
11*	10.3	1.38	1.73	0.78	0.18	0.08	89.3%
mean	17.0	4.9	1.52	0.69	0.25	0.11	82.5%
median	17.0	4.6	1.52	0.69	0.25	0.11	83.0%
max	23.7	8.9	1.73	0.78	0.35	0.16	90.0%
min	10.3	1.3	1.32	0.60	0.17	0.08	73.8%

Table 7. Phosphorus data for case studies where both urine diversion and composting technologies were used. Loads are calculated per year. *Water usage assumed for calculations. Underline denotes assumed initial concentration based on Lowe et al.[4] Dataset 6A includes only samples taken after occupants reported septic tank had reached full capacity; dataset 6B includes all post-installation samples.

Discussion:

Overall Results

With limited participation in this study, and with several case studies requiring the use of assumed data, the ability to draw significant findings is limited. However, it appears that those cases that utilized composting toilets as the main collection of sanitary waste, whether on its own or with the use of vacuum flush or urine diversion, significantly reduced the amount of nitrogen and phosphorus being released into the environment. There is general agreement that composting toilets are an effective way to reduce water use in a home, although the efficacy of these systems for nutrient management has not been empirically validated.

This study focused on the task of quantifying the performance of various eco-toilets (composting and urine diverting strategies) in achieving nutrient reduction. In the five case studies (1, 2, 5, 7 and 9) where composting toilets were installed such that all toilet waste entered a composting reactor, a mean reduction of approximately 86% TN and 82% TP was observed in wastewater entering the household septic system. In Case Studies 3, and 6 where there was a partial diversion of fecal matter from a less-used toilet, a mean reduction of 80% TN and 83% TP per capita were observed from the septic system (accounting for assumptions noted above). Case study 11, where all toilet waste is diverted to either a compost bin or a urine collection tank, shows a per capita reduction of TN of 90% and 90% TP.

Urine diversion toilets appear to be less reliable, although, they too show a reduction in nutrients. The results (discounting Case Study 10) show a mean TN reduction of approximately 48% and a mean TP reduction of 23%. While all of the various eco-toilets appear to be a viable strategy for the stated levels of nutrient removal, eco-toilets that divert all of the toilet waste (urine, feces and toilet paper) appear to achieve the highest load reductions.

General Feedback by Residents

Overall, case study participants reported a favorable experience with their composting toilets. In one instance, installation of the composting toilet avoided the need for a costly septic system replacement (estimated at >$15,000). Another property that installed both urine diverting and composting toilets reported a total installation cost of approximately $12,000 before the $5,000 town incentive was applied. Weekly "hands-on" maintenance was indicated in the case of larger units, while more frequent attention was required for the self-contained unit of Case Study 5, where someone was generally in the home all day.

Periodic occurrences of flies and gnats were reported as well. One owner conveyed that the recommended larvicide Gnatrol® did not adequately control flies and fungus gnats. Back-up batteries for the fan unit are being utilized at multiple locations to ensure continued fan operation and odor control during a power outage.

The disposal of liquid residual was a concern in all cases and was particularly problematic in the case of the self-contained unit (Case Study 5), when excess liquid spilled out of the collection pan on a number of occasions. This required the unit to be set completely level for maximum liquid storage. Case Study 7 reported a high volume of leachate theorized to be related to the vacu-flush systems being utilized at this location; a subsequent adjustment was made to reduce the amount of liquid per flush. Case Studies 2 and 9 also reported high volumes of leachate with the use of only gravity toilets.

Owners of urine diverting toilets reported some overall difficulty in use, specifically for women and children. However, manufacturers do offer a seat that is specifically designed for children to reduce this difficulty. The low flow nature of the technology also made it more difficult to discharge solids into the system. Multiple locations noted the need for extra flushing and/or cleaning to convey feces from the toilet.

Residual Disposal

Residuals refer to the solid compost and liquid leachate generated by a composting toilet. By regulation, the finished solid compost residual may be buried beneath six inches of cover by the toilet owner and the leachate must be transported by a licensed septage hauler or diverted to the septic system.[5] When nutrient management in a watershed is desired, neither onsite disposal strategies are appropriate since they release varying amounts of nitrogen into the watershed that may exceed the limit necessary to protect natural resources.

This project did not examine strategies to manage the solid compost, but it is assumed that if composting toilets are widely used, a regional facility for processing residuals would be necessary. To examine disposal options for the liquid residual, ten 5-gallon portions of compost leachate were submitted to Mark Hutchinson at the University of Maine School of Composting. The goal of the experiment was to determine whether the residual liquid could be used in conjunction with a compost feedstock to create a usable soil amendment made devoid of human pathogens by way of thermophilic composting. Thermophilic composting uses bacteria that can tolerate high temperatures (>50^{o}C) to break down waste and kill pathogens. Three potential feedstocks were chosen for experiments based on availability in our area: oak leaves, used horse bedding (containing additional nitrogen from horse urine and manure) and wood shavings. Concentrations of nitrogen in the liquid residual generally ranged from 1–3 grams/L and TP levels ranged from 0.6–1.2 grams/L. The experiments concluded that compost leachate added to the aforementioned feedstocks would not support the thermophilic composting process needed to render pathogens harmless.

Disposal of urine collected from urine diverting toilets is also an issue. Currently, urine is pumped by a licensed septage hauler and discharged at a septage disposal facility. Owners from Case Study 10 reported having to pump their 150-gallon urine tank every six to seven months at an approximate cost of $300. While there are some studies underway at the Rich Earth Institute to determine beneficial reuses for urine (http://richearthinstitute.org/), the most effective disposal site is a wastewater treatment plant.

Although the term nitrogen "reduction" is used in this report when referring to composting toilets, the reader should understand that preventing nitrogen from entering the groundwater system is not truly achieved unless nitrogen present in the residuals (leachate and solid compost) is removed from the watershed system being considered. Accordingly, when eco-toilets are used in context of a management plan to meet nutrient reduction to loads, the residual products must be managed to ensure that they are not applied to the watershed in any manner that can result in the eventual leaching of nitrogen into groundwater systems. Currently, Massachusetts regulations that allow burying solid compost beneath six inches of soil[5] do not aid in such efforts. Similarly, the use of compost leachate to irrigate plants in the watershed (which might appeal to some individuals) may also result in the release of nitrogen to groundwater resources.

Although only a few aspects of eco-toilet operation and maintenance are covered in this report, we did attempt to address options for disposal of the composting toilet residuals (leachate and compost). The data suggest that an average home with two adults might produce 50–150 gallons of leachate per year that will not evaporate during the composting process. This liquid is 98.2% water and adding it to a carbon-rich compost operation does not result in the thermophilic composting necessary to ensure pathogen destruction.[6] These authors indicate that for every 1,000 gallons of tea produced, approximately 1,600 cubic yards of dry carbon material would be required to control the moisture. This would not significantly enhance the nutrient content of the compost for soil amendment. Accordingly, at this time, the only acceptable management of the liquid residual appears to be removal by a licensed septage hauler and disposal at a wastewater treatment facility. Some experiments have shown that by mixing feces, food waste and amendment, it is possible to reach temperatures that might reduce pathogens.[6] Further study is needed to explore a viable management strategy.

Data from the sites where urine was diverted to a holding tank are limited. If this strategy is to be evaluated further based on these data, the cost and benefits might be compared with advanced alternative onsite treatment systems that generally have similar load removals.

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<u>Appendix 1</u>

CWMP Update – Chapter 3: Pilot Projects

Draft 2/6/2018

3.2. Eco-Toilets

3.2.1 Introduction

In 2010, as part of the public discussion process on the Draft Comprehensive Wastewater Management Plan, an organized group of citizens urged the Town to evaluate what role Eco-toilets could play in reducing the need for conventional sewering with all of its attendant monetary and energy costs. Town Meeting and the voters passed Article 17 in 2011 that included an allocation of $500,000 for studying composting, packaging and urine-diverting toilets and denitrifying septic components. The purpose was to provide in situ information on the use and function of these systems in homes and businesses and to determine their acceptability and effectiveness.

Eco-toilets separate human feces and urine from the wastewater system of a house or business. Once this source separation occurs, the human waste can be composted on-site, or treated in a centralized facility. The human-derived residue is then useable as a soil amendment that is rich in nutrients. The expense of sewer infrastructure is avoided, and operation and maintenance costs are vastly cheaper.

3.2.2 Eco-Toilet Pilot Projects

Falmouth completed a pilot project to evaluate the nitrogen-removal, costs and public acceptance aspects of eco-toilets, which can be either composting or urine-diverting fixtures or combinations thereof. The Eco-Toilet Incentive Program (Program) was designed to provide information on the following:

- Nitrogen-removal efficacy of eco-toilets, for TMDL-compliance
- Total installed costs, including labor and materials
- Critical factors involved in installation as well as operation and maintenance
- Public acceptance

To encourage participation in this voluntary project, three different incentive programs over a three-year period were provided:

- Up to $5,000 incentive and a septic system pump-out valued at approximately $300 for any home or business in Falmouth that would install eco-toilets in all its bathrooms;
- An exemption from an estimated $17,000 betterment assessment for over 1200 homes in the Little Pond Sewer Service Area;
- Up to $10,000 incentive for any home within 300 feet of West Falmouth Harbor as part of the West Falmouth Harbor Shoreline Septic Remediation Program

These financial incentives were well-publicized to encourage participation in the Program. First, every Falmouth residence received a colorful notice in its water bill advertising a $5000 incentive for installing eco-toilets. In addition to this mailing, marketing efforts included regular articles in the local newspaper, attendance at community events such as a concert in 2012 and the weekly Falmouth Farmer's Market and workshops held by a local non-profit, The Green Center. These outreach and promotional efforts generated a list of 170 interested people. Each of these homeowners was contacted by phone about the Program. Ultimately ten [10] homeowners participated by installing eco-toilets in their bathrooms through these public information initiatives.

To encourage additional participation, over 1200 homeowners in the Little Pond Sewer Service Area (LPSSA) were mailed a letter from the Town alerting them to the option of installing eco-toilets instead of paying an estimated $17,000 betterment. Two homeowners initially enrolled from the LPSSA, but subsequently dropped out of the Program and instead hooked-up to the sewer system. A third initiative offered homeowners within 300 feet of West Falmouth Harbor a $10,000 incentive to install eco-toilets or Innovative/Alternative septic systems. None of the the 30 participants in this project selected eco-toilets. Public participation in the Demonstration was low in Falmouth, despite significant financial incentives and ongoing promotion to encourage participation.

Of the 170 people who showed initial interest in eco-toilets, 55% indicated they ultimately chose not to participate due to factors such as the effort involved in ongoing operation and maintenance of the eco-toilet and a concern over resale value of the home. Cost was only a factor for 10% of respondents who did not choose to participate.

Eco-Toilet Demonstration Program Final Statistics

Number of people contacted: 170

Number of people with site visits:..50

Number of people who installed eco-toilets:...10

Types of installations/eco-toilets chosen:

Full range, including central composters, self-contained units, urine-diverting fixtures

3.2.3 Eco-Toilet Performance Monitoring, Installation Costs and Operation and Maintenance

The Barnstable County Department of Health and Environment (BCDHE) monitored all ten eco-toilet systems that were installed as part of this Program and reported on the measured nitrogen-removal. BCDHE found that composting toilets removed 85% of nitrogen that would otherwise enter a septic system; urine-diverting toilets that only divert urine from the septic system removed 50% of the nitrogen. This report, entitled XXX is included in Appendix X.

In addition to their nitrogen-removal effectiveness, the cost and practicality of retrofitting existing structures with eco-toilets is critical to an evaluation of whether these toilets are a viable alternative to more traditional wastewater management techniques. The Town of Falmouth Eco-Toilet Incentive Program Final Report (DATE) is included in Appendix X and provides technical details for the different eco-toilet systems that were installed, costs (including labor and materials) as well as findings related to public acceptance. In summary, costs (including labor and materials) to install eco-toilet system in one, first-floor bathroom ranged from $2,600 for a small, self-contained unit where the bin holding excrement and urine is directly below the toilet bowl to $9,500 for a central composting unit with a remote bin. Additional bathrooms cost approximately $2,500 each to retrofit.

Operation and maintenance of eco-toilets includes weekly maintenance of composting bins as well as residuals management. Residuals include compost (feces and urine mixed with wood shavings) and leachate, which is the excess liquid that is not taken up during the process of composting. Leachate accumulates at approximately 2 gallons/person/month. Urine diverting toilets require the regular removal of urine from a holding tank. Regular turning and ultimate burial of compost is usually done by the homeowner but hauling of residuals and urine must be performed by a licensed septic hauler. All eco-toilets require some form of residuals management.

3.2.4 The key findings of eco-toilet pilot project are:

- Measured nitrogen removal for composting systems is 85% and for urine-diverting fixtures is 50%
- Installation costs of most systems are significant for existing homes with more than one bathroom, ranging from $2600 to $9500 per unit
- Homeowners must make a commitment to maintain their eco-toilets. Operation and maintenance includes removing compost and disposing of liquids such as urine and leachate
- Homeowner acceptability of installing eco-toilets is low

Homeowner concern with re-sale value of dwelling is high

Based on these conclusions, eco-toilets are not included as a separate non-traditional technology for watershed planning purposes. They continue to be listed as an Innovative/Alternative (I/A) septic system option. In watersheds where I/A septic systems are the recommended solution for TMDL-compliance, property owners will also be able to select eco-toilets that achieve the same level of nitrogen-removal as is required for I/A septic systems.