Investigation of the Treatment of Drip Dispersal Onsite Septic Systems for the Removal of Selected Micro-Constituents and Contaminants of Emerging Concern

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Prepared by

George R. Heufelder, M.S., R.S.

and

Bethany Sadlowski, B.A., R.S.

Barnstable County Department of Health and Environment
Superior Courthouse, Route 6A
Barnstable, Massachusetts 02630

Prepared For

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Executive Summary

A preliminary investigation regarding the removal of selected Contaminants of Emerging Concern (CEC) by shallow soils-based onsite septic system technologies was conducted at the Massachusetts Alternative Septic System Test Center in 2010 – 2012. Untreated septic tank effluent was applied to a shallow (less than 9 inches) soil horizon in lined test cells. We report that removal efficiencies of selected pharmaceuticals, hormones and personal care products in drip dispersal systems are generally higher than those levels reported for non-soils-based treatment technologies. The removal efficiencies of the selected compounds using drip dispersal reported approach 100%. The data suggest that septic systems employing shallow soils-based means for ultimate disposal may offer comparable to better treatment for certain micro-constituents of wastewater compared to some municipal wastewater treatment facilities. The fire retardant TCEP (Tris (2-chloroethyl) phosphate) was not attenuated during treatment and, similar to the conclusion reached in other studies, may prove to be a particular challenge for wastewater treatment removal strategies.

One additional objective of the present study was to evaluate the effect of supplementing the drip dispersal system with air. Additional air (3 – 5 psi @ 3 – 5 cfm) was provided through the drip dispersal network at times when effluent was not being applied. Soil-gas measurements revealed no significant and consistent differences in the achievement of atmospheric levels of oxygen between the treatments. Accordingly, the absence of significant differences between CEC removal efficiencies may not be representative of the impacts of supplemental-air. It is posited that the small orifices of the drip system may not allow enough air into the immediate soil profile in significant amounts higher than that of the natural air movement in the non-treated test cells.

Introduction

This project follows research completed by the Barnstable County Department of Health and Environment in cooperation with the United States Geologic Survey (USGS), with the purpose of investigating the treatment of selected alternative onsite septic systems for Contaminants of Emerging Concern (CEC). Early results indicated that a standard soil absorption system receiving septic tank effluent removed more CEC than certain advanced onsite septic system treatment components (M. J. Zimmerman 2005; M. Zimmerman and Heufelder). Preliminary investigations (unpublished data) further suggested that shallow-horizon distribution systems, such as drip dispersal and shallow drainfield systems, might offer additional removal of CEC presumably due to their position in a more biologically-active soil layer and their proximity to the plant root zone.

The goal of this study was to determine the capability of shallow soils-based onsite septic system technology to remove selected CEC. In particular, we investigated drip dispersal technology, which uses ½ inch tubing equipped with small orifice emitters that “drip” filtered septic tank effluent to the soil along the length of the distribution tube. The pipe is usually six to ten inches below the surface. The broader distribution of effluent in small doses onto the soil interface near the plant root zone was theorized to enhance treatment for a variety of traditionally-observed contaminants such as fecal indicators, biochemical oxygen demand, total suspended solids, nutrients and others.

In July 2010, seven test cells containing drip dispersal piping were constructed side-by-side at the Massachusetts Alternative Septic System Test Center (MASSTC). Each cell was 30 feet in length and five feet wide. Four emitter lines with emitters located at 24-inch intervals were laid in parallel within each cell. All test cells were underdrained to collect the wastewater as it percolated through the underlying soil. Three of the seven cells were supplied with only septic tank effluent, three cells were additionally equipped with the ability to introduce air at selected intervals, and finally, one cell was equipped with drip tubing but no supply of wastewater or air. This cell was used as a control to determine rainfall amounts potentially contributing to the dilution of compounds. A schema of a typical test cell is provided in figure 1, while pictures of the installation are provided in figure 2.

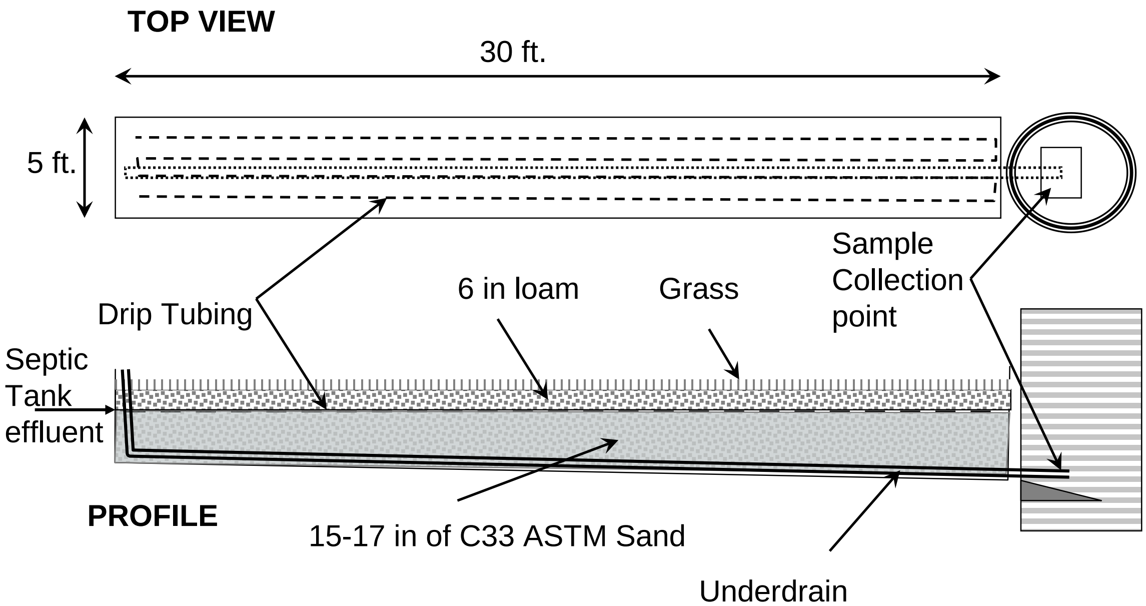

Figure 1. Schemata of drip dispersal test cells as constructed at the Massachusetts Alternative Septic System Test Center in June 2010.

The underdrain of each test cell was directed by pipe into a Dipper™ distribution box (shown in fig. 2f). The device tipped each time approximately one gallon of percolate filled the tipping pan, while a data logger recorded the number and timing of each tip. By this means, the volume of percolate was approximated and compared to the known and calibrated volume supplied to the drip system test cell. The reader is reminded that shallow soils-based systems promote evapotranspiration during the warmer summer months, thereby concentrating soluble wastewater constituents and reducing wastewater percolate volume. This phenomenon subsequently results in less tips than predicted based on the wastewater volume supplied to the drip system. Conversely, during precipitation events, the volume of percolating precipitation dilutes the wastewater and adds to the total volume of percolate, resulting in more tips than predicted based on the wastewater supplied to the system. The effects of evapotranspiration and precipitation on the concentration of dissolved constituents could be determined, therefore, by comparing predicted percolate volume (based on actual calibrated influent volume) with estimated percolate volume using data collected from the tipper. The control test cell provided an additional estimate of precipitation inputs and evapotranspiration by means of comparison with other cells. Tipper pans were removed during sampling procedures.

Figure 2. a.) Cell liner installed with sloped sides (toward center drain) and washed peastone around distally-sloped center drain; b.) drip tubing placed within each cell, 16 inches on center, and outer tubing lengths six inches from liner sides; c.) drip tubing with two inches of sand cover before loam cover; d.) two inches of loam spread and raked into sand cover to provide sand-loam transition; e.) finished cells with sod in place; f.) tipper tray inside riser receiving bottom drain pipe—note magnetic-switch operated data logger for recording approximate volume by number of tips.

Samples were taken in one liter amber glass bottles containing the preservative sodium azide and transported on ice to the University of Massachusetts Amherst, Special Environmental Analysis Program; a joint effort between the Environmental Analysis Laboratory and the University of Massachusetts Amherst Environmental & Water Resources Engineering Program. Table 1 provides a list of compounds examined in each of the three sampling rounds; November 9, 2010, October 11, 2011 and July 15, 2012.

Compound	Use	Included in November 9, 2010 Sampling Round	Included in October 11, 2011 Sampling Round	Included in July 15, 2012 Sampling Round
Acetaminophen	Analgesic		X	X
Atenolol	Cholesterol control		X	X
Atorvastatin	Heart medication, beta-blocker	X *	X	X
Caffeine	Stimulant	X	X	X
Cimetidine	Ulcer medication	X	X	
Ciprofloxacin	Antibiotic	X	X	X
Cotinine	Nicotine metabolite	X *	X	X
DEET	Insect repellant	X	X	X
Diclofenac	Anti-inflammatory		X	X
Diltiazem	Blood pressure medicine	X *	X	
Diphenhydramine	Antihistamine	X	X	X
Doxorubicin	Cancer therapy		X	X
Estradiol	Hormone		X	X
Estrone	Hormone		X	X
Furosemide	Diuretic		X	X
Gemfibrozil	Anti-cholesterol		X	X
Ibuprofen	Analgesic		X	X
Metformin	Diabetes medicine	X		
Miconazole	Anti-fungal agent	X *	X	X
Naproxen	Anti-inflammatory	X	X	X
Primidone	Anticonvulsant			X
Propranolol	Beta-blocker	X	X	X
Ranitidine	Ulcer medication		X	X
Salbutamol (Albuterol)	Bronchodilator	X *	X	X
Sulfamethoxazole	Antibiotic	X	X	X
TCEP	Flame retardant	X	X	X
Thiabendazole	Anthelmintic	X *		
Trimethoprim	Antibacterial	X	X	X
Warfarin	Anticoagulant	X *	X	X
Xanthine	Bronchodilator	X *		
* Indicates that the compound was not found at or above the detection limit.				

Table 1. List of Contaminants of Emerging Concern (CEC) assayed in three sampling rounds taken at the Massachusetts Alternative Septic System Test Center 2010–2012.

Wastewater Influent

Wastewater in this study originates from a combination of three sites: residential military housing, an elementary school and a county jail. The wastewater was intercepted from a municipal treatment plant collection line and distributed to a number of different onsite septic system technologies. The drip system wastewater influent was first supplied to a 1500-gallon septic tank which flows by gravity into a 1000-gallon pump chamber. From the pump chamber, wastewater was dispersed under pressure to the six test cells. Dosing volumes were determined by a modified control panel that also allowed intermittent introduction of air to three of the six test cells. Supplemental air was supplied under 3 – 5 psi at a rate of 3 – 5 scfm to the cells in 10 daily cycles of an approximate 1hr 10min duration. Approximately 230 gallons/day were dispersed equally among the six test cells, which were each equipped with 60 ± 2 pressure-compensated emitters. Wastewater was supplied in 20 doses over a 24 hour period. Supplemental air was introduced into drip cells 5 – 7 at a pressure of 3 – 5 psi and a flow rate of 3 – 5 scfm. The combination of the dosing rate and the density of drip emitters, prevented soil gas concentrations from approximating atmospheric levels of oxygen, carbon dioxide, methane and hydrogen sulfide; as measured in the soil gas monitoring ports.

Treatment Process Summary

In summary, the treatment process can be described as primary settling of raw wastewater in a septic tank with an approximate six-day retention time, followed by conveyance through a drip dispersal system and passage through 15–17 inches of ASTM C33 sand. A vertical profile of two inches immediately beneath the emitter elevation was comprised of ASTM C33 sand and loamy soil comparable to that imported with the overlying sod. The average hydraulic loading rate considering the area of each cell (150 sq ft) was approximated at 0.26 gal/day/sq ft.

Lessons Learned

This report summarizes data from three sampling rounds. The initial round in November 2010 followed the first growing season of the drip dispersal system sod. Immediately prior to this round, we were confident that air supply to the three trenches was functioning properly. Accordingly, data suggested differences between the typical drip dispersal systems and those enhanced with air, which validated the systems' proper operation. Following the second round in October 2011, however, we discovered problems with the dispersal and air pumps in the air enhanced cells. We were unable to determine how long the problem occurred. While wastewater effluent was still being dispersed into the cells, it is likely that there was no air-supply for an undetermined period prior to the time of sampling.

To address operational uncertainties, we made a number of changes in 2012 that allowed for verification of system functionality. First, a discharge emitter from each treatment (air and no-air) was removed and inspected for potential problems. It was determined that the air supplied cells had exhibited excessive organic buildup in the distribution tubing. This corroborated our belief that air was not being supplied as we had thought, and that the air pump had ceased to function months prior to the second round of sampling. The distribution lines were thoroughly flushed to eliminate this organic buildup. Second, although the motor of the air supply pump appeared to have been running, it was found not to be supplying air. We replaced the pump and placed a pressure and volume gauge in the air supply line to be checked and logged daily.

Finally, to further verify aeration status in the soil surrounding all test cells, air-gas sampling points were placed in the distal end of the cells for weekly sampling, which began two weeks prior to and throughout the July 2012 sampling round. In addition, we performed a number of measurement series at the start of the air pump cycle to understand how air affects the cycle over time. Wastewater samples in July 2012 were accompanied by a series of soil-gas measurements to compare differences between treatments (air vs. no air). These measurements were correlated with oxygen levels in the surrounding soil during the treatment period.

In summary, the first round of samples taken in November 2010 reflects the performance of the drip dispersal system both with and without the introduction of air through the emitters. Although we had hoped to duplicate these results in the second round of sampling, we now understand that conditions during sampling in October 2011 did not replicate those of 2010 due to a malfunction resulting in a lack of air supply to the systems. Nevertheless, these samples add significantly to our understanding of the treatment in a standard drip system. During the third round of sampling, we were able to verify air flow to the soil profile. Further, the third round of sampling incorporated duplicate samples taken approximately 30 minutes following the initial sample.

Data Considerations

Levels of CEC in aqueous samples collected were assessed using LC/MS/MS with prior solid phase extraction by the University of Massachusetts Environmental Engineering Laboratories. Analysis involved a Fluid Management Systems solid phase extraction sample preparation system and a Waters Acquity UPLC coupled to a Micromass Quattro Premier triple quadrupole mass spectrometer. The values were obtained using standard quality control including analysis of external instrument standards.

Many CEC have extremely low detection levels, which warrants an explanation of the complexities involved in data interpretation. First, it should be understood that CEC analyses are strongly affected by the matrix assayed; in this case, raw wastewater versus treated wastewater. Some researchers report that levels of certain CEC in raw wastewater may be over five times higher than indicated by analyses due to the matrix effect (Snyder et al. 2003). With advancing levels of treatment, analytical methods have the capability to better approximate true values. In addition, the recovery rate (ability to recover a known amount of compound from a spiked sample) may be low in many compounds, further complicating data interpretation.

A final consideration in this study was the constraining influence of sample analysis costs, which limited the number of samples and hence the ability to perform robust statistical comparisons. Despite this fact, we believe the results broadly represent the degree to which shallow drip dispersal systems are able to attenuate selected CEC.

The wide variety of characteristics in compounds examined (including their polarity, reactivity, and sensitivity to pH and other matrix qualities) dictates that there is no simple and logical order for the presentation of results. We have chosen to present compounds in decreasing order of assay recovery rate. Since the recovery rate represents the amount of compound from a spiked sample that is recovered during analysis, it serves as a representation of the analysis accuracy for a given analyte. Recovery rates near 100% indicate that the analytical method is accurate, since nearly all of a compound in the sample would be accounted for in the result. This ensures well-supported conclusions. Conversely, recovery rates below 100% compel a more generalized interpretation of the data. Further, the occasional report of recovery rates in excess of 100% indicate a lack of precision in the method or spiking technique, since theoretically one could not recover more compound than was initially spiked into the sample. In these instances, we interpret that the data support conclusions similar to compounds showing 100% recovery, with an understanding that the precision precludes robust statistical comparisons. Those compounds for which no recovery rate was specified are presented last.

Results

Raw data for all analytes is provided in Appendix 1.

Naproxen

Naproxen is an over-the-counter non-steroidal anti-inflammatory drug that works by reducing hormones that cause inflammation and pain in the body resulting from conditions such as arthritis, tendinitis, bursitis, gout or menstrual cramps. Naproxen is commonly found in wastewater of many countries, including the wastewater and surface waters of North America and Europe (Peng et al. 2008). In the present study, the first round of sampling in 2010 indicated substantially higher percolate levels of naproxen than those observed in 2011 and 2012 (fig. 3).

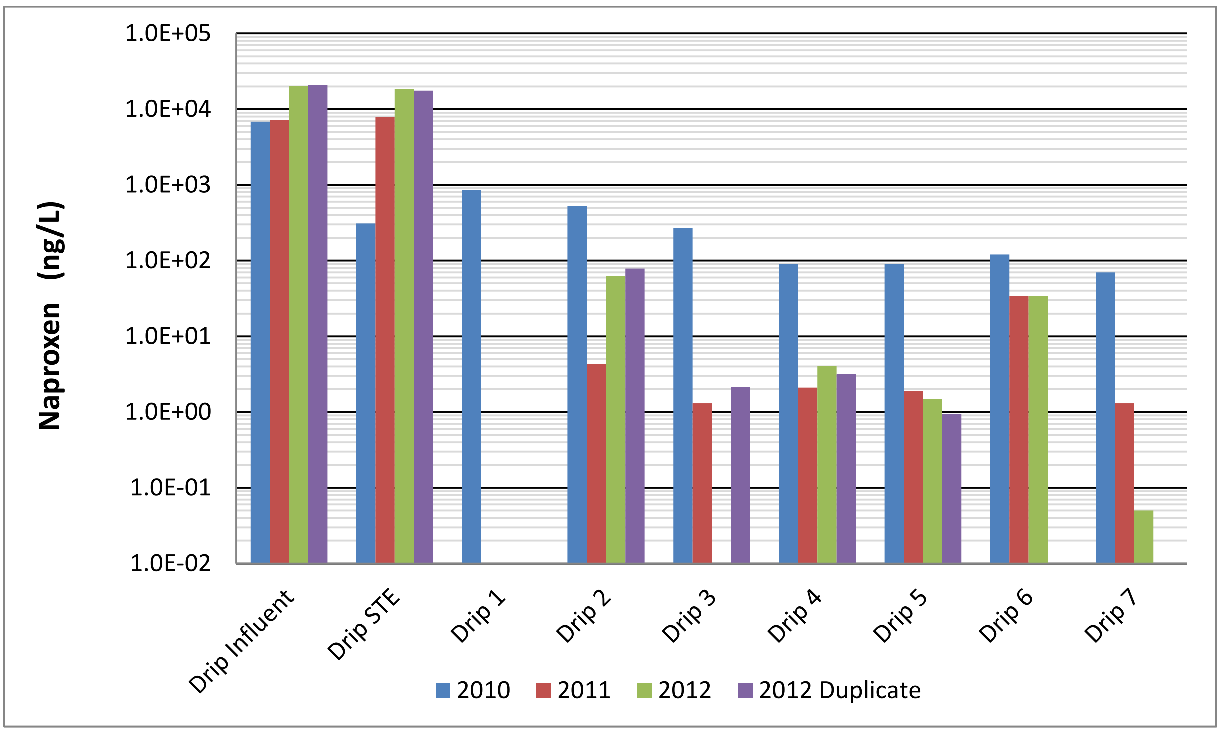

Figure 3. Concentration of naproxen in samples taken 2010–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center. Drip 1 is a control (no wastewater); Drip 2–4 were not provided supplemental air; Drip 5–7 were supplemented with air as described above. STE = septic tank effluent.

The average removal of Naproxen by drip dispersal is 99.9% (fig. 4). Data summarized from various wastewater treatment plants (Schröder 2010; Ying, Kookana, and Kolpin 2009) suggest that the drip dispersal system has a higher removal efficiency than certain centralized wastewater treatment technologies. In addition, the drip system reported higher removal efficiencies than a number of small scale onsite wastewater treatment technologies such as by sand filters, horizontal subsurface flow and vertical flow constructed wetlands (Matamoros et al. 2009). The reason for the substantial increase in Naproxen removal between 2010 and successive years may reflect the effects of the soil profile conditioning by wastewater flora. The substantial reductions of Naproxen during the treatment process have been theorized by some to be the result of a high dissociation constant and subsequent availability of the compound for microbial degradation (Stafford 2008). No obvious correlation of removal rates in the drip system with the enhancement of oxygen was noted.

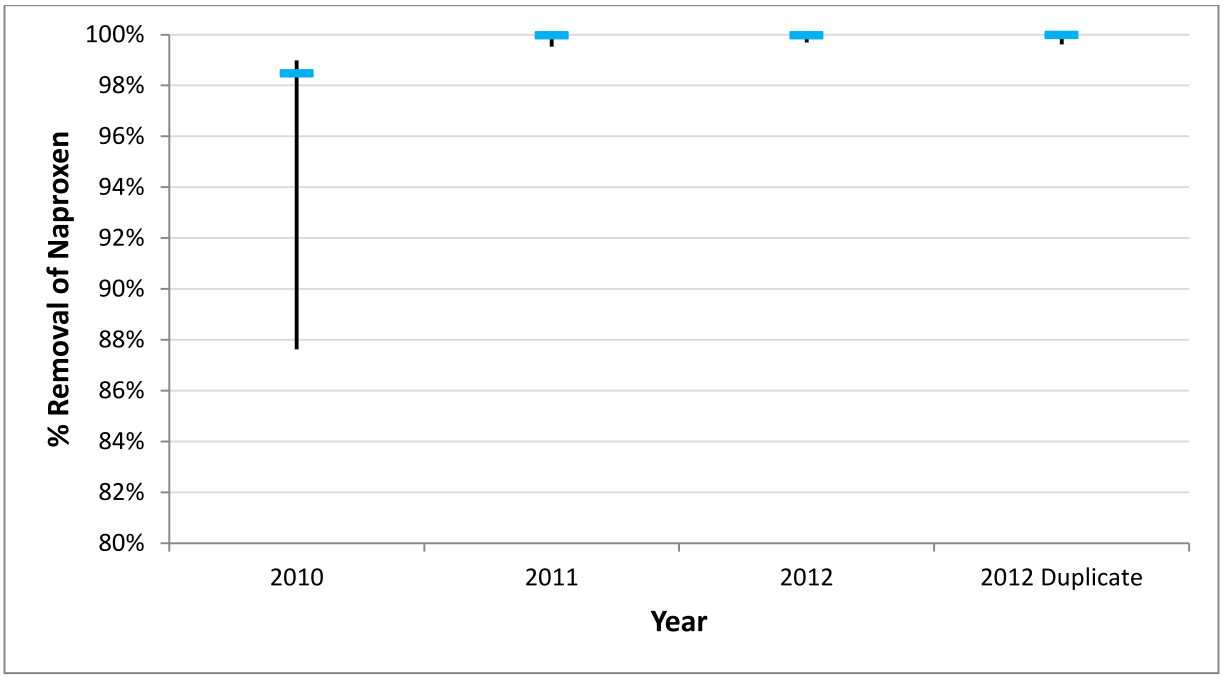

Figure 4. Percent removal of Naproxen in drip dispersal system as indicated by averaging percolate samples collected 2010–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center (median removal and range illustrated n=6 per year).

Estrone and Estradiol (17ß-estradiol)

Estrone and estradiol are natural hormones produced by vertebrates. Estrone is also found in some fruits. As steroid hormones, their release to the environment has potential for disrupting normal endocrine function in human and wildlife populations. Daily excretion of estrone has been estimated at 3.9 µg for males, 3–20 µg for females and 600 µg for pregnant females (Ying, Kookana and Ru 2002). Daily excretion of estradiol is estimated by these authors as 1.6 µg for males, 2.5–3.5 µg for females and 259 µg for pregnant females. Both compounds were assayed in October 2011 and July 2012, but were not assayed in earlier samples.

Concentrations of estrone are inextricably linked with those of estradiol since the latter readily oxidizes both abiotically and biologically to form estrone (Ying, Kookana, and Ru 2002). Indeed, with the persistence of estrone, the data generally show a reduction in estradiol with progressive treatment (fig. 5).

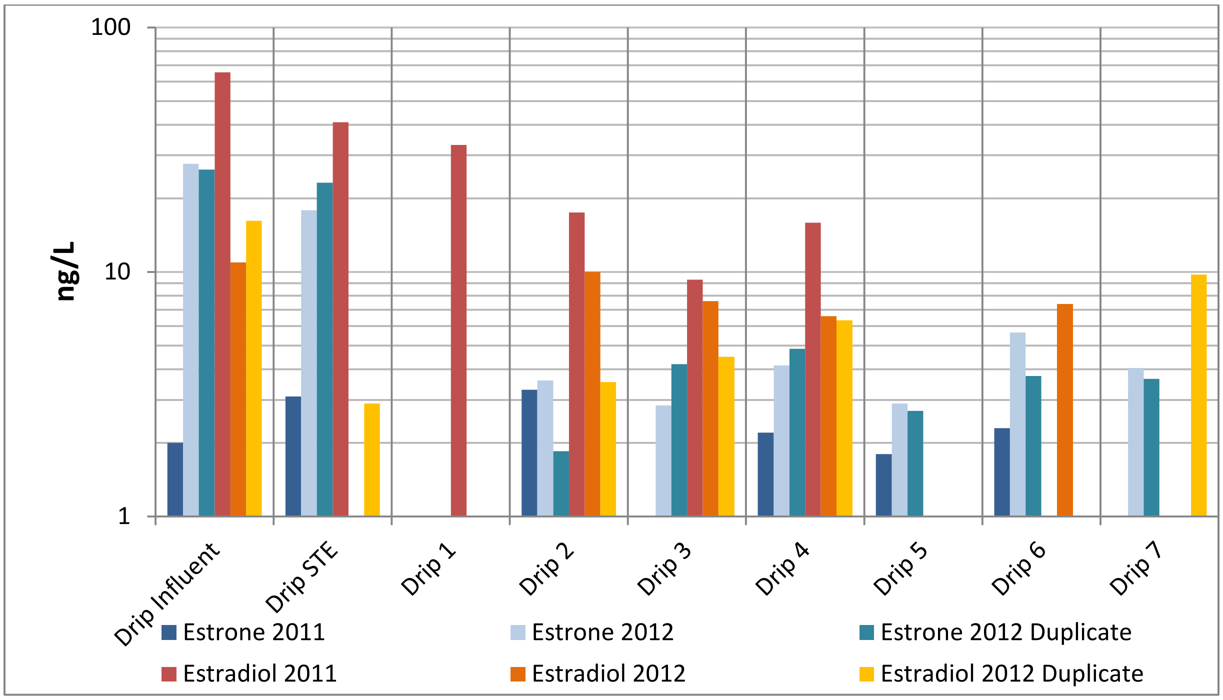

Figure 5. Concentrations of estrone and estradiol in samples taken 2011–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center. Drip 1 is a control (no wastewater); Drip 2–4 were not provided supplemental air; Drip 5–7 were supplemented with air as described above. STE = septic tank effluent.

Studies from other areas (Ying, Kookana, and Kumar 2008; Ying et al. 2008) suggest that aerobic environments are optimal for estrogen compounds to degrade, while anoxic treatment systems have limited ability to attenuate these compounds. There is also some suggestion that the more aerobic cells (5–7) were more conducive to the metabolism and/or abiotic oxidation of estradiol (two exceptions noted). The unusually high level of estradiol in Drip 1 in 2011 cannot be explained.

Diltiazem

Diltiazem is a prescription pharmaceutical used to treat high blood pressure and control angina (chest pain). It belongs to a class of medications called calcium-channel blockers and works by relaxing blood vessels so that the supply of oxygen to the heart muscle is enhanced. This compound was found in one of 47 groundwater samples at a maximum concentration of 28 ng/L during a national surveillance study (Barnes et al. 2008). It was found more frequently in a national surveillance study of surface waters, with 11 of 84 samples determined to have a median concentration of 21 ng/L (Kolpin et al. 2002). Despite influent concentrations of this compound exceeding 100 ng/L, one researcher found that diltiazem was absent in the effluent of a wastewater treatment plant during a screening level study (Godfrey and Woessner 2004). In this study, influent levels of diltiazem were found to be at least 500 ng/L and showed reductions in the drip system of 60–90% (fig. 6). In 2010, diltiazem was not found at levels above the detection limit. This compound was not assayed in 2012.

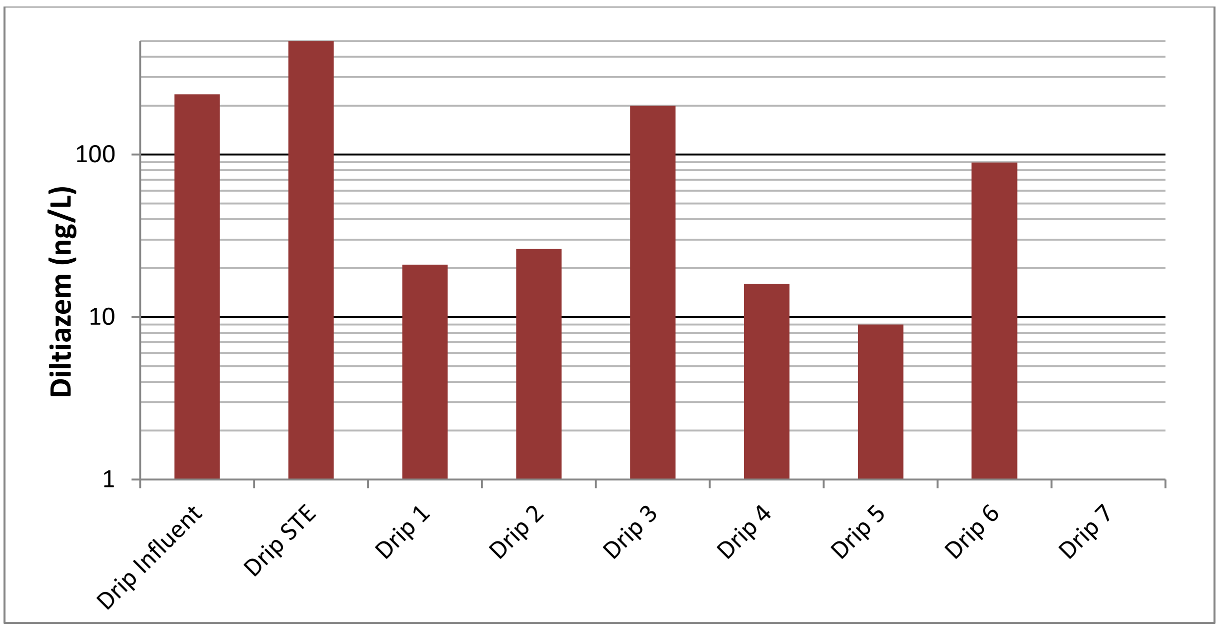

Figure 6. Concentration of diltiazem in samples taken October 2011 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center. Drip 1 is a control (no wastewater); Drip 2–4 were not provided supplemental air; Drip 5–7 were supplemented with air as described above. STE = septic tank effluent.

TCEP Tris(2-chloroethyl)phosphate

Tris(2-chloroethyl)phosphate (TCEP) is an alkyl phosphate ester used as a flame-retardant plasticizer and viscosity regulator in polyurethanes, polyester resins, polyacrylates and other polymers. One of the eleven most common compounds found in a drinking water survey of 19 U.S. water utilities at a median level of 120 ng/L (Benotti et al. 2008), TCEP is a suspected endocrine disruptor. Both sampling rounds in the present study suggest that this compound persists through the soils-based wastewater treatment process even when it is air-enhanced (fig. 7). The apparent increases in concentration from influent to percolate are likely due to inherent underestimation of concentrations in the raw-wastewater matrix; a problem previously discussed.

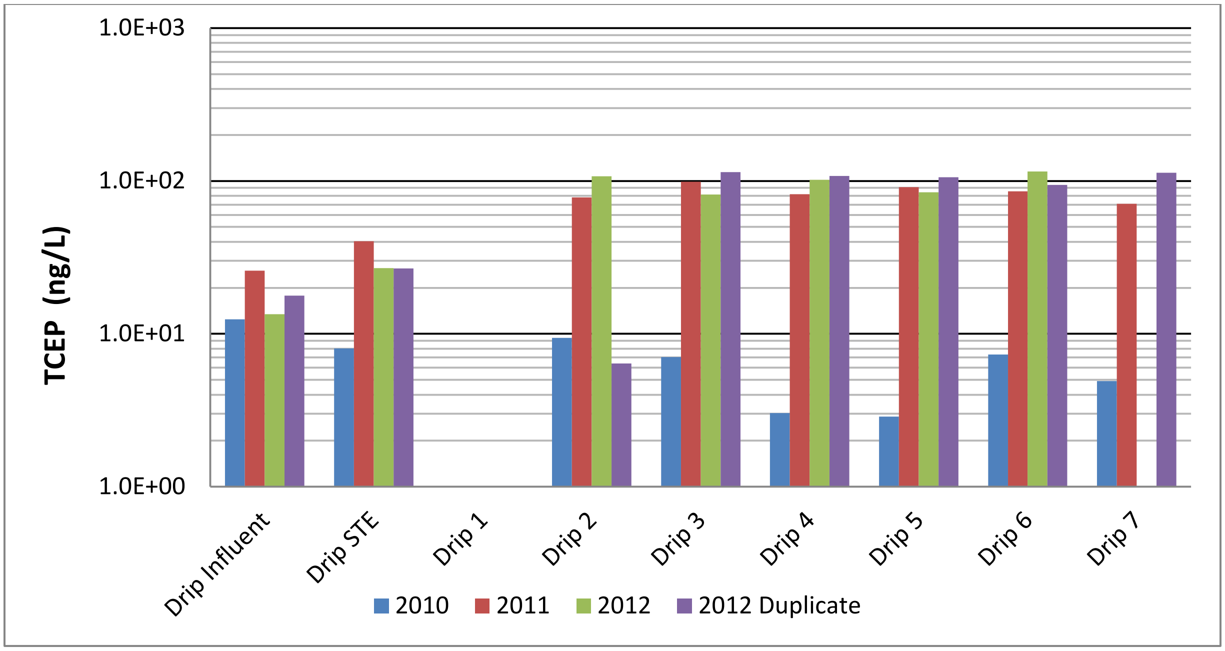

Figure 7. Concentration of TCEP in samples taken 2010–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center. Drip 1 is a control (no wastewater); Drip 2–4 were not provided supplemental air; Drip 5–7 were supplemented with air as described above. STE = septic tank effluent.

DEET (N,N-diethyl-meta-toluamide)

DEET is a commonly used insect repellant that enters the wastewater stream through bodily washing and laundry wash water. According to some studies, secondary treatment of wastewater is reported to remove 69% ± 21% of DEET (Sui et al. 2010). Other studies report less success (<50%) at removing this compound with secondary treatment (Oppenheimer et al. 2007). Our sample results suggest that soils-based treatment can achieve >95% removal of DEET. There is also some suggestion that removal level improves over time (figs. 8 & 9).

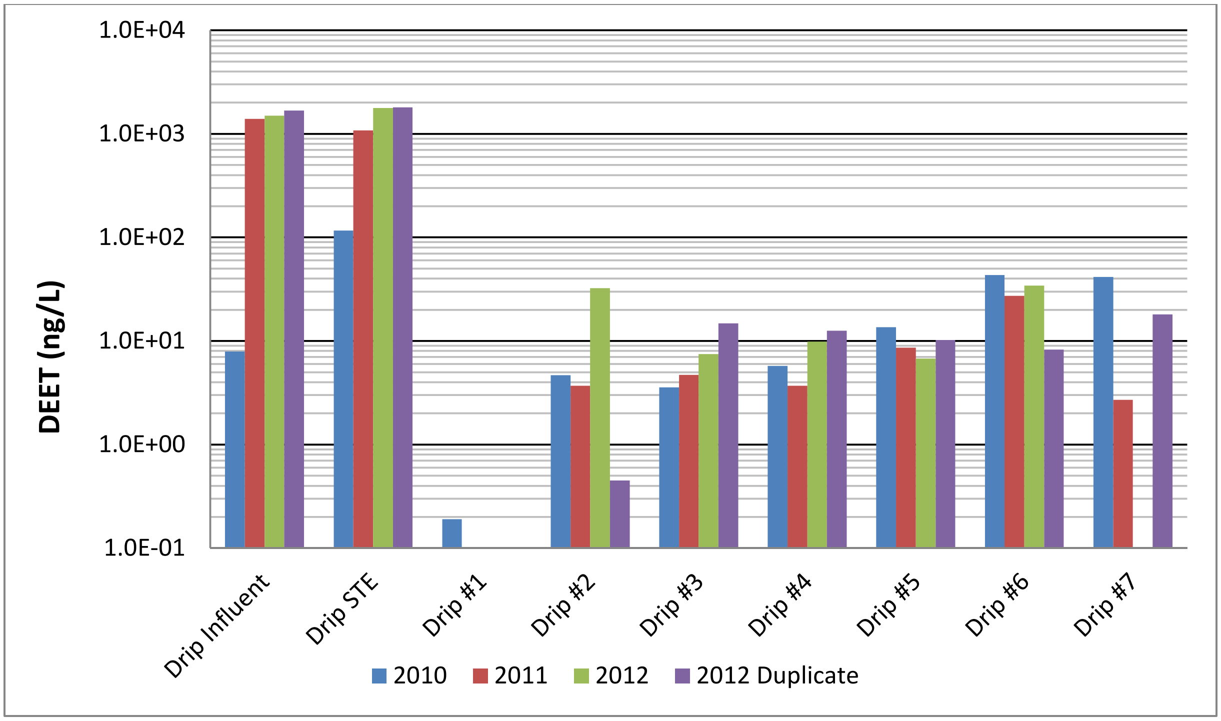

Figure 8. Concentration of DEET in samples taken 2010–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center. Drip 1 is a control (no wastewater); Drip 2–4 were not provided supplemental air; Drip 5–7 were supplemented with air as described above. STE = septic tank effluent.

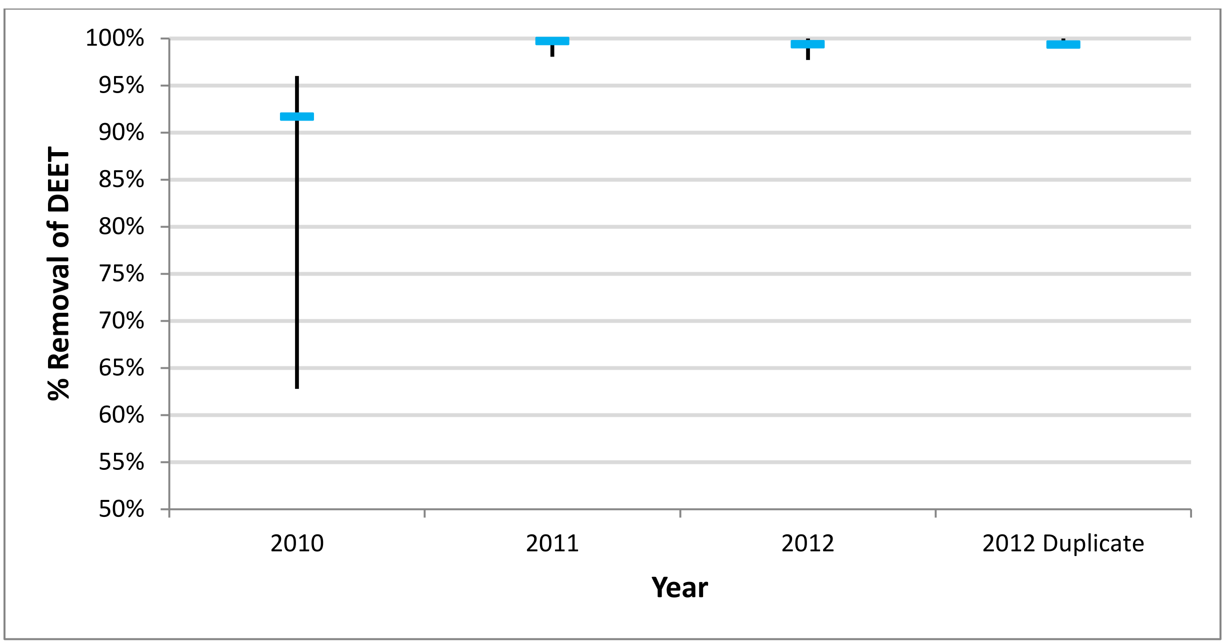

Figure 9. Percent removal of DEET in drip dispersal system as indicated by averaging percolate samples collected 2010–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center (median removal and range illustrated n=6 per year).

Trimethoprim

Trimethoprim is a prescription antibiotic used to combat urinary tract and other infections. Some researchers indicate that trimethoprim is excreted unchanged from the recipient at a rate of 80% (Kasprzyk-Hordern, Dinsdale, and Guwy 2009). The present study suggests that soils-based treatment nearly eliminates trimethoprim from wastewater, with >98.7% removal (figs. 10 & 11). This removal efficiency is generally higher, with one exception, than removal values reported for selected municipal treatment plants (Schröder 2010).

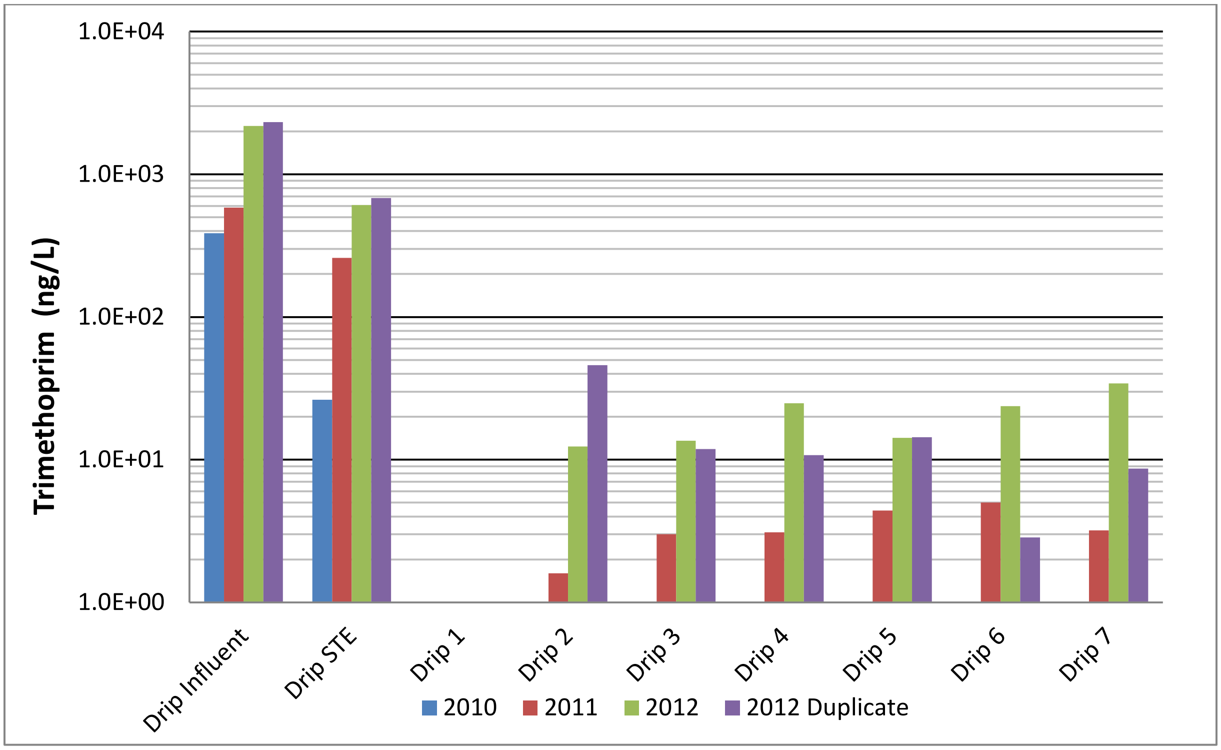

Figure 10. Concentration of trimethoprim in samples taken 2010–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center. Drip 1 is a control (no wastewater); Drip 2–4 were not provided supplemental air; Drip 5–7 were supplemented with air as described above. STE = septic tank effluent.

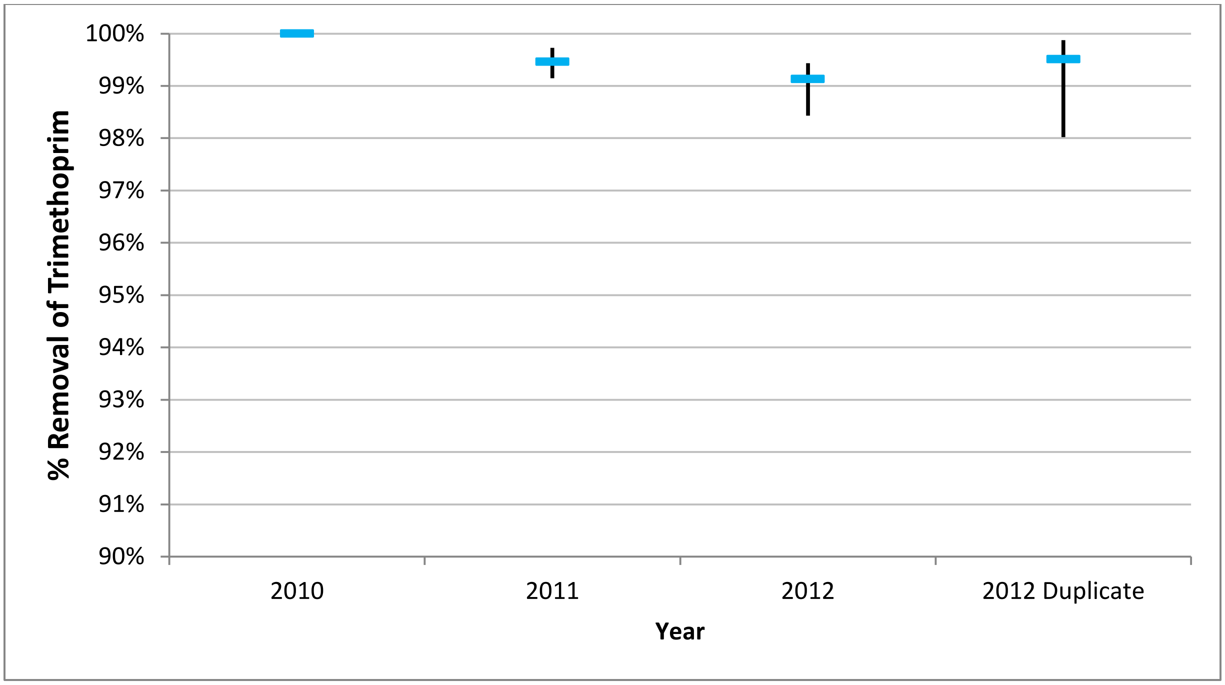

Figure 11. Percent removal of trimethoprim in drip dispersal system as indicated by averaging percolate samples collected 2010–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center (median removal and range illustrated n=6 per year).

Ranitidine

Ranitidine is an antacid histamine blocker used to treat ulcers and gastro esophageal reflux disease. Over-the-counter ranitidine is used to prevent and treat symptoms of heartburn and acid indigestion. It is commonly found in wastewater treatment plant influents and effluents (Rosal et al. 2010; Polar 2007; Kasprzyk-Hordern, Dinsdale, and Guwy 2008; Gros et al. 2010). The near complete removal of ranitidine in the present study (fig. 12) concurs with other authors who observed similar results beneath soil absorption systems (Godfrey and Woessner 2004). It should be noted however that this compound was not assayed in 2010; during the analyses in 2012 the instrument did not demonstrate an adequate calibration and data are not included here.

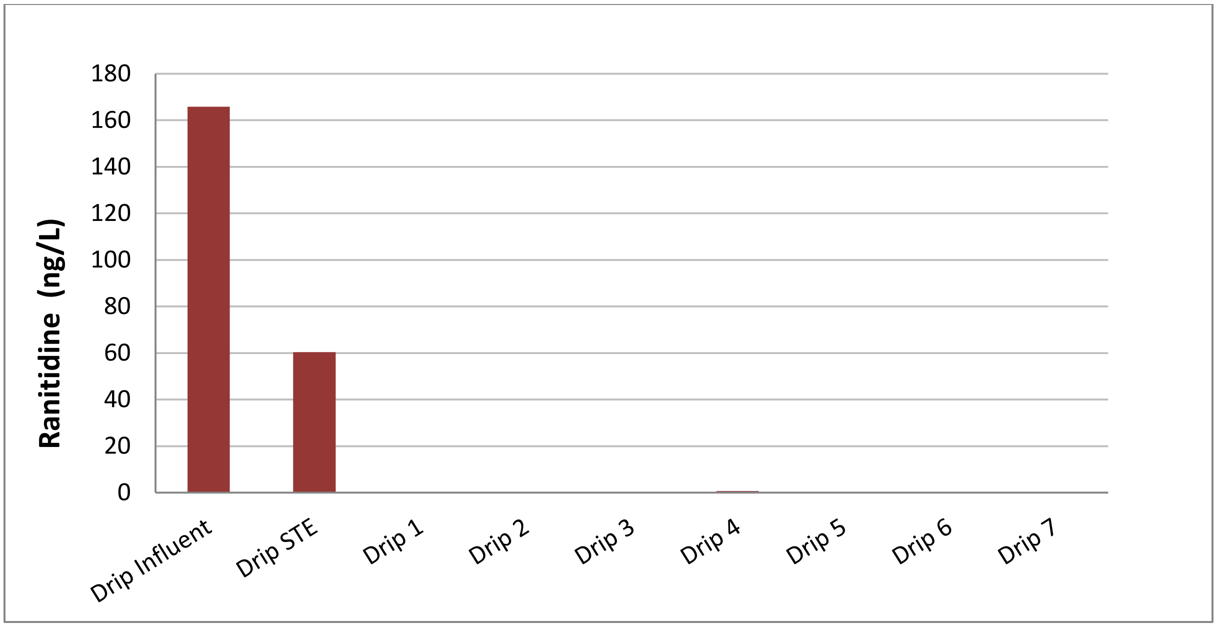

Figure 12. Concentration of ranitidine in samples taken in October 2011 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center. Drip 1 is a control (no wastewater); Drip 2–4 were not provided supplemental air; Drip 5–7 were supplemented with air as described above. STE = Septic Tank Effluent.

Furosemide

Furosemide is a potent diuretic used to eliminate water and salt from the body and is sometimes used in conjunction with other drugs to control high blood pressure. Forty to sixty-seven percent of furosemide ingested is secreted in urine unchanged, and some investigators have noted that furosemide is estrogenic (Fatta-Kassinos, Meric, and Nikolaou 2011). We most commonly observed removals exceeding 95% for furosemide in the drip system in 2011 and 2012 (figs. 13 & 14); this compound was not assayed in November 2010**.**

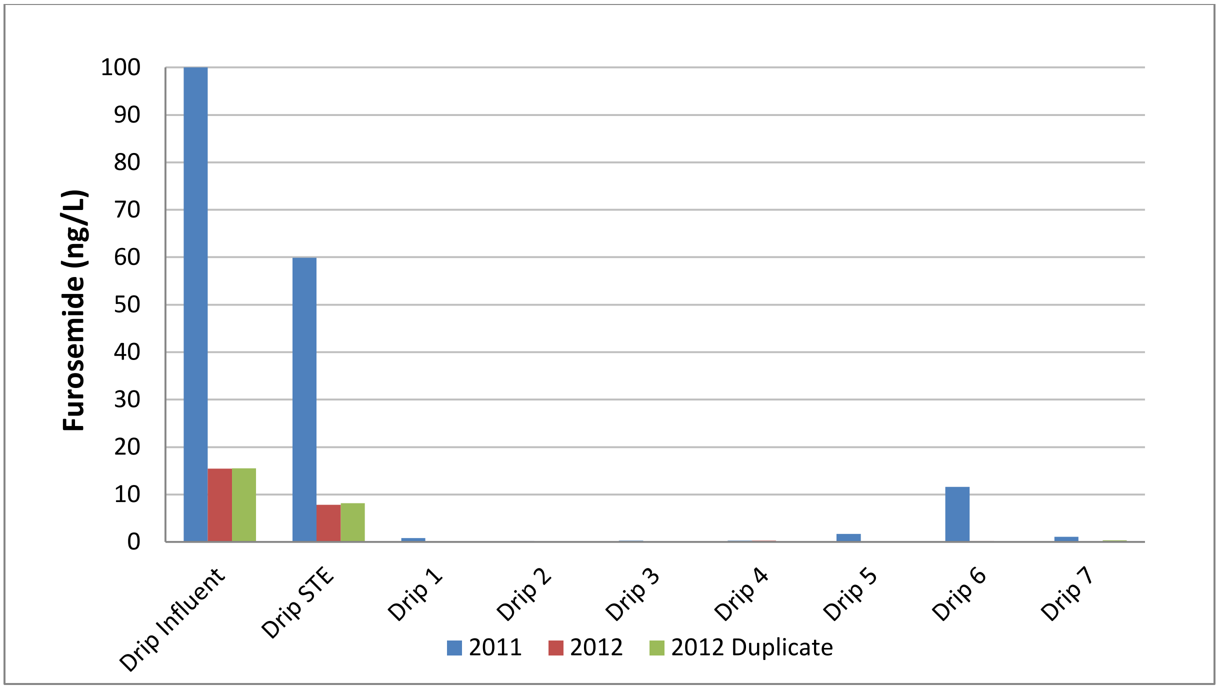

Figure 13. Concentration of furosemide in samples taken 2011–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center. Drip 1 is a control (no wastewater); Drip 2–4 were not provided supplemental air; Drip 5–7 were supplemented with air as described above. STE = septic tank effluent.

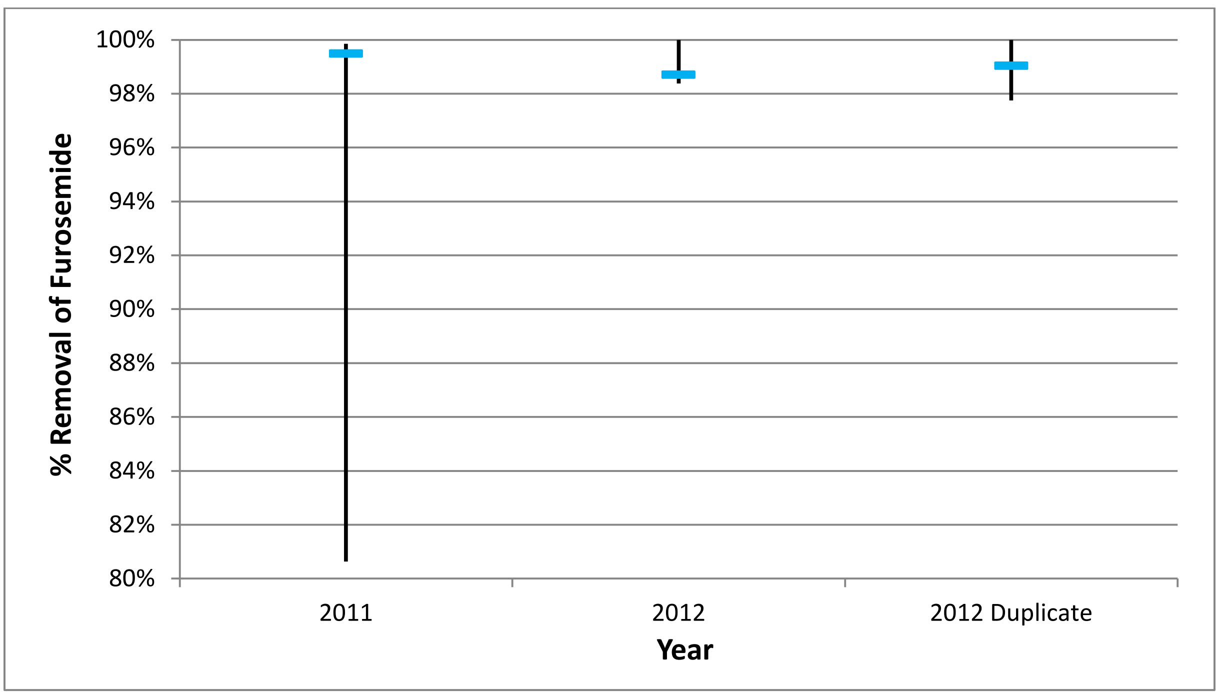

Figure 14. Percent removal of furosemide in drip dispersal system as indicated by averaging percolate samples collected 2011–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center (median removal and range illustrated n=6 per year).

Warfarin

Warfarin is a prescription drug used as a blood thinner to reduce blood clotting. Although this study and others (Wilcox et al. 2009) report recovery rates approaching 50% for septic tank effluent, Warfarin was absent from septic tank effluent in the present study. Warfarin was detected however in all six percolate samples of the drip dispersal system in concentrations ranging from 2.1–9.3 ng/L (mean 4.6 ng/L) in 2011 and ranging from 0.5–7.3 ng/L (mean 3.6 ng/L) in 2012. The presence of Warfarin in percolate concurrent with its absence in septic tank effluent is unexplained but likely caused by the difficulty in extracting Warfarin from raw and primary treated wastewater.

Salbutamol (Albuterol)

Salbutamol, a short-acting prescription drug used to relieve bronchospasms, is inhaled during treatment. This compound was not found in samples during November 2010, but it was found in influent and septic tank effluent at concentrations of 38.1 ng/L and 41.5 ng/L respectively in October 2011. At that time, Salbutamol was not detected in percolate of the drip dispersal system.

Contrary to expectations, a higher concentration of Salbutamol was noted in the septic tank effluent compared with the influent. This same trend was also observed in 2012; septic tank effluent concentrations of 25.7 ng/L were observed concurrent with concentrations of 14.5 and 16.7 ng/L in the wastewater influent. This may reflect a difficulty in extracting Salbutamol from the raw wastewater matrix. Observations in 2011 and 2012 (figs. 15 & 16) suggest >95% removal in shallow soils-based systems. Various authors (Kasprzyk-Hordern, Dinsdale, and Guwy 2009) report removal from nearly 90% to zero removal during various municipal treatment processes.

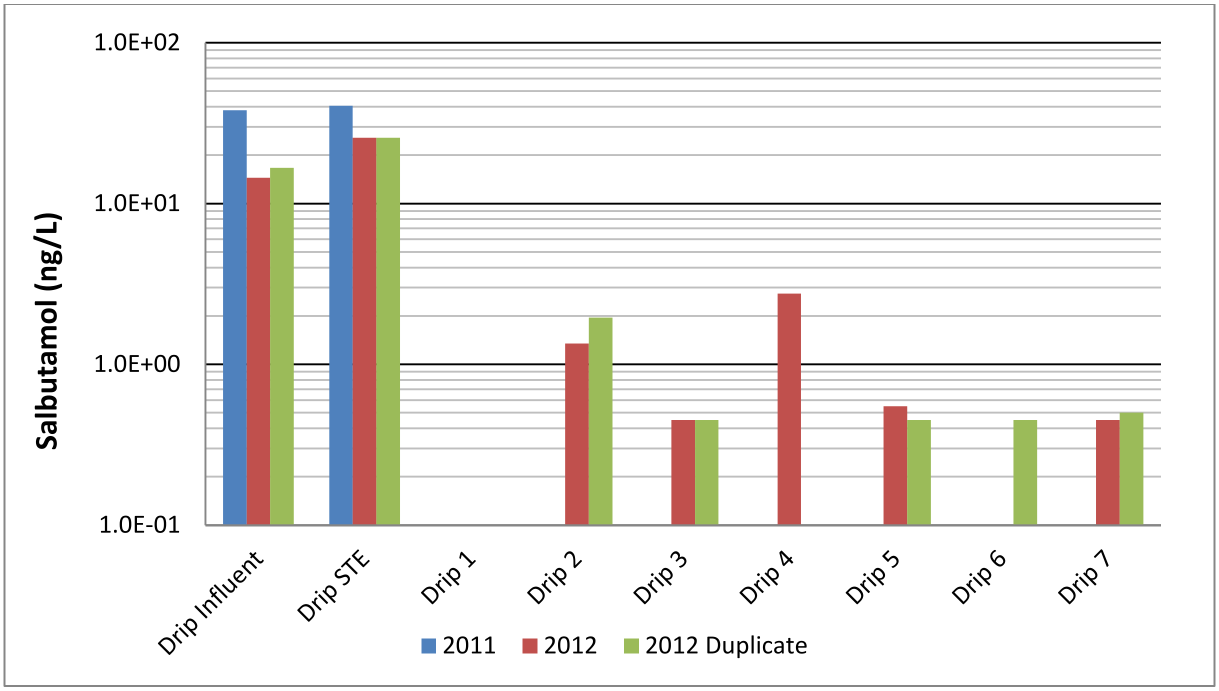

Figure 15. Concentration of Salbutamol in samples taken 2011–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center. Drip 1 is a control (no wastewater); Drip 2–4 were not provided supplemental air; Drip 5–7 were supplemented with air as described above. STE = septic tank effluent.

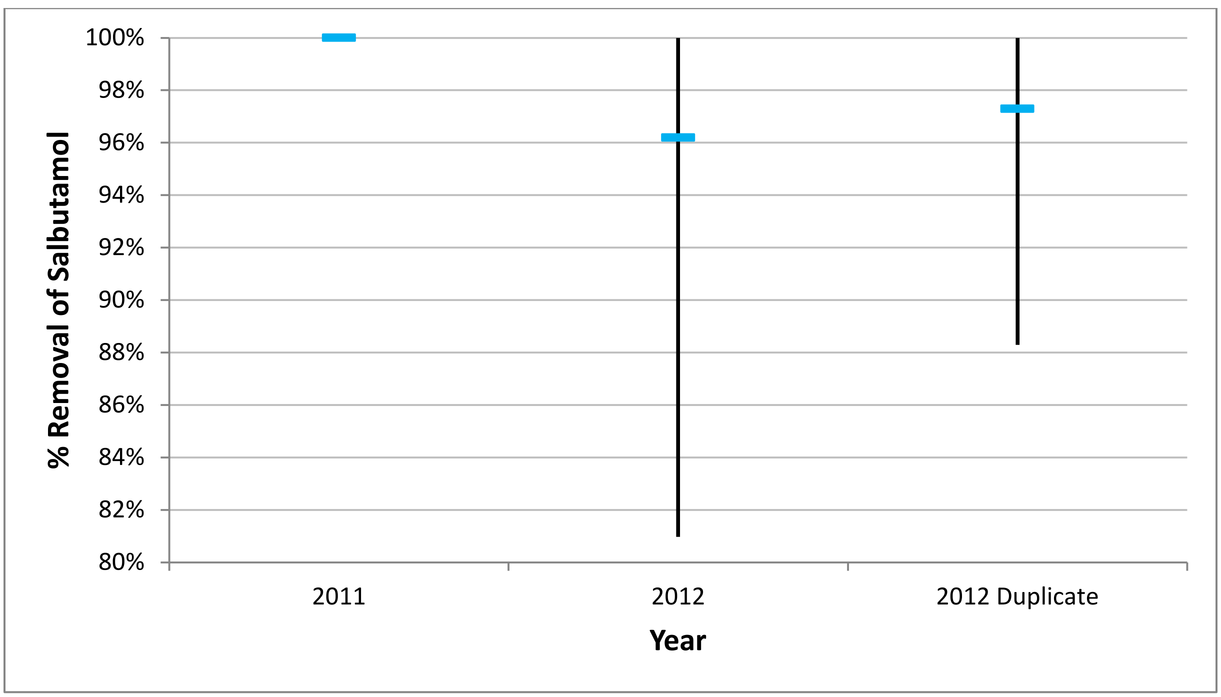

Figure 16. Percent removal of Salbutamol in drip dispersal system as indicated by averaging percolate samples collected 2011–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center (median removal and range illustrated n=6 per year).

Propranolol

Propranolol is a beta-blocker used to treat hypertension, anxiety and panic. It was the first successful beta-blocker developed. It is a common micro-constituent found in wastewater and certain surface waters (Rosal et al. 2010; Mompelat, Le Bot, and Thomas 2009; Heberer 2002). Propranolol was found in comparatively low concentrations during November 2010 compared with 2011 and 2012 (fig. 17). The removal rate approximating 60% is better than that reported for activated sludge treatment (Rosal et al. 2010) (fig. 18).

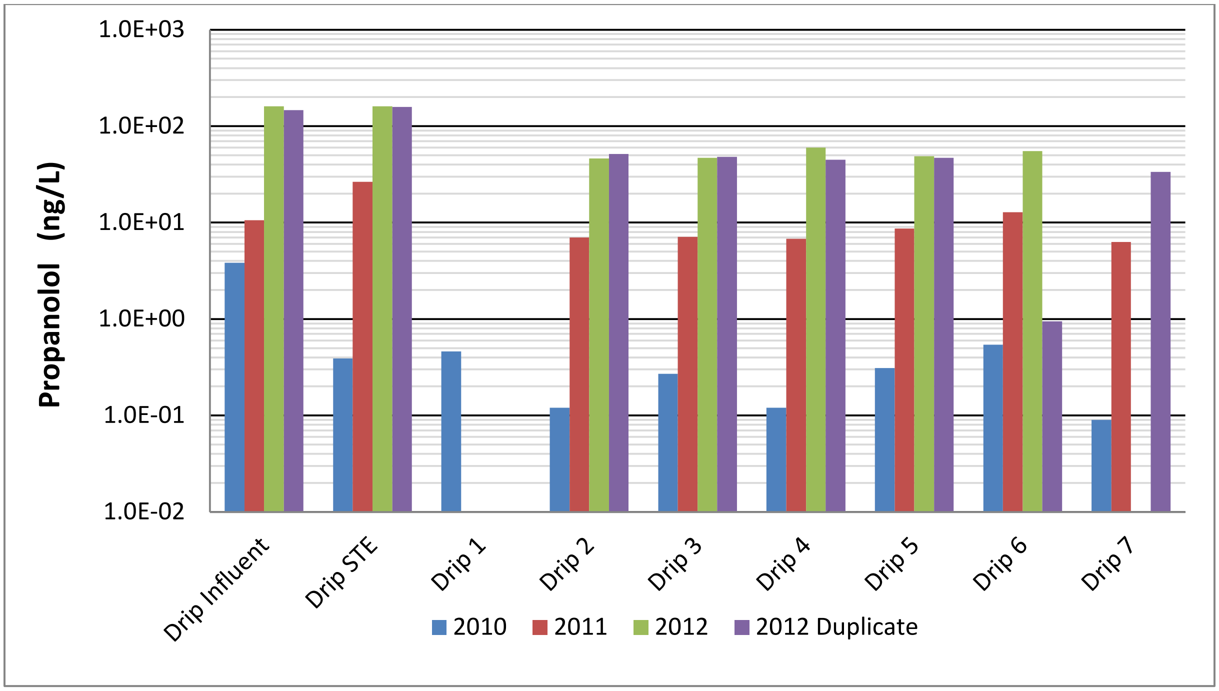

Figure 17. Concentration of propranolol in samples taken 2010–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center. Drip 1 is a control (no wastewater); Drip 2–4 were not provided with supplemental air; Drip 5–7 were supplemented with air as described above. STE = septic tank effluent.

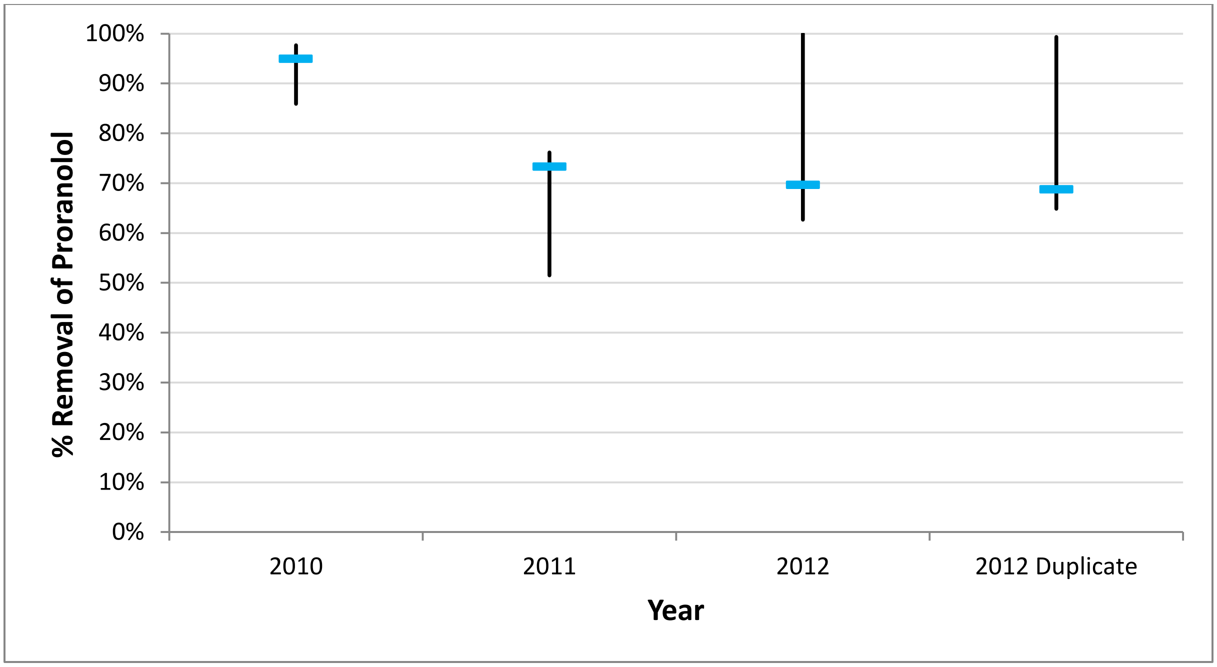

Figure 18. Percent removal of propranolol in drip dispersal system as indicated by averaging percolate samples collected 2010–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center (median removal and range illustrated n=6 per year).

Diphenhydramine

Diphenhydramine is a commonly used non-prescription antihistamine. Despite its occurrence in the influent during November 2010 (31.8 ng/L), October 2011 (190 ng/L) and July 2012 (150–168 ng/L), none was found in the drip dispersal system percolate on either date suggesting near complete removal in the treatment process.

Caffeine

Caffeine is a common stimulant found in many foods and drinks. It is perhaps the most common contaminant found among the micro-constituents, in fact, some researchers have proposed its use as an indicator of domestic pollution (Seiler et al. 1999). In the present survey, caffeine reductions in the drip dispersal system exceeded 99.9% (figs. 19 & 20). There is some indication from data collected in November 2010 that enhancing the soil profile with oxygen reduced treatment effectiveness, however, during the 2011 and 2012 sampling rounds, percolate from all cells appear similar but still exceed 99.9% reduction.

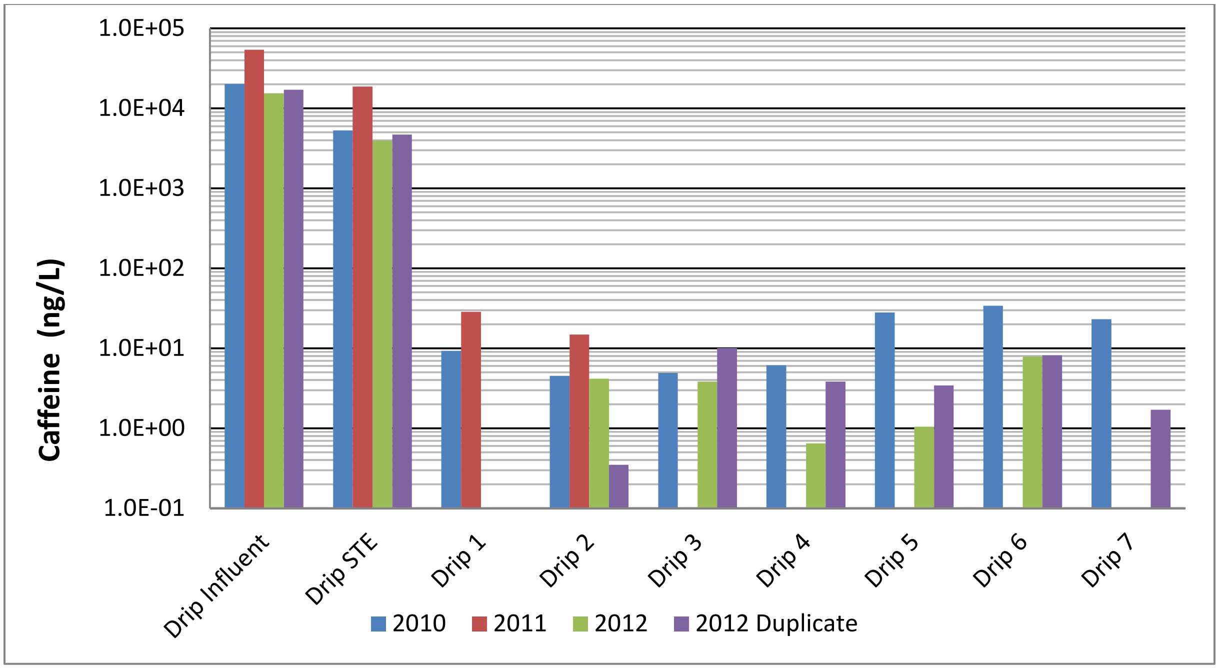

Figure 19. Concentration of caffeine in samples taken 2010–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center. Drip 1 is a control (no wastewater); Drip 2–4 were not provided supplemental air; Drip 5–7 were supplemented with air as described above. STE = septic tank effluent.

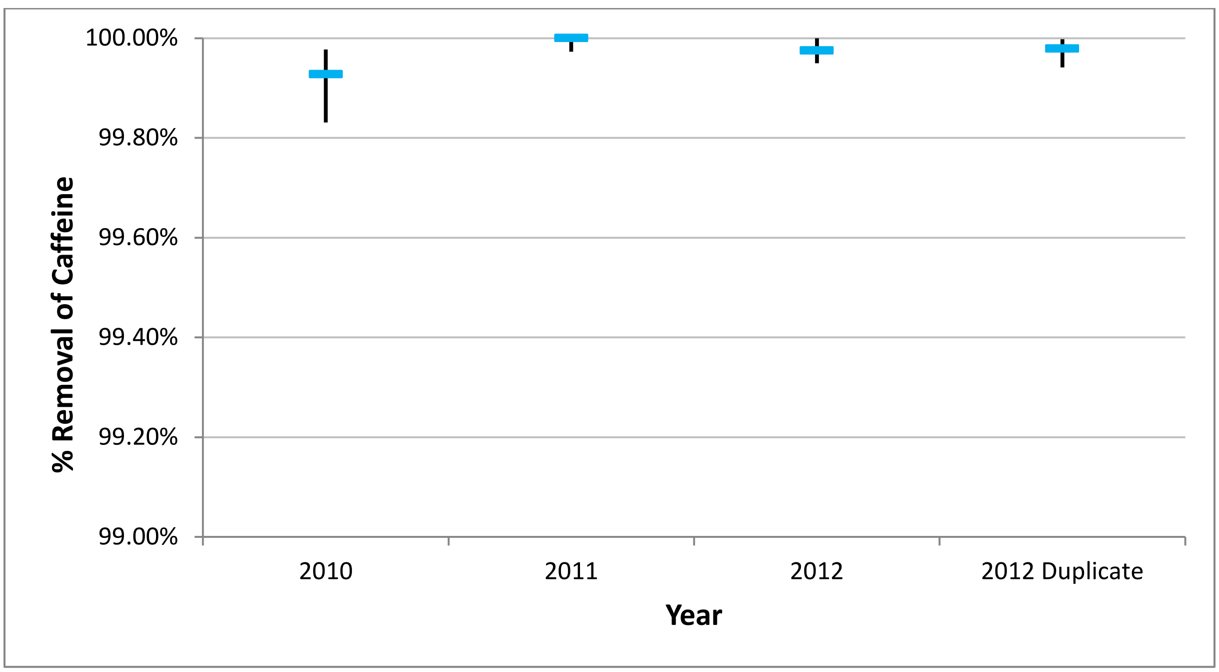

Figure 20. Percent removal of caffeine in drip dispersal system as indicated by averaging percolate samples collected 2010–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center (median removal and range illustrated n=6 per year).

Gemfibrozil

Gemfibrozil is in a class of lipid-regulating medications called fibrates. A combination of filtration (sand), clarification, Granulated Activated Charcoal adsorption and chlorination unit processes was reported to remove more than 90% of influent levels (Kumar, Chang, and Xagoraraki 2010). With few exceptions, sampling results from 2011 and 2012 suggest a similar removal rate for the drip dispersal system (figs. 21 & 22). This compound was not found in November 2010. The generally-higher concentrations of gemfibrozil in septic tank effluent compared to raw wastewater suggest a matrix-extraction difficulty with raw wastewater compared with septic tank effluent.

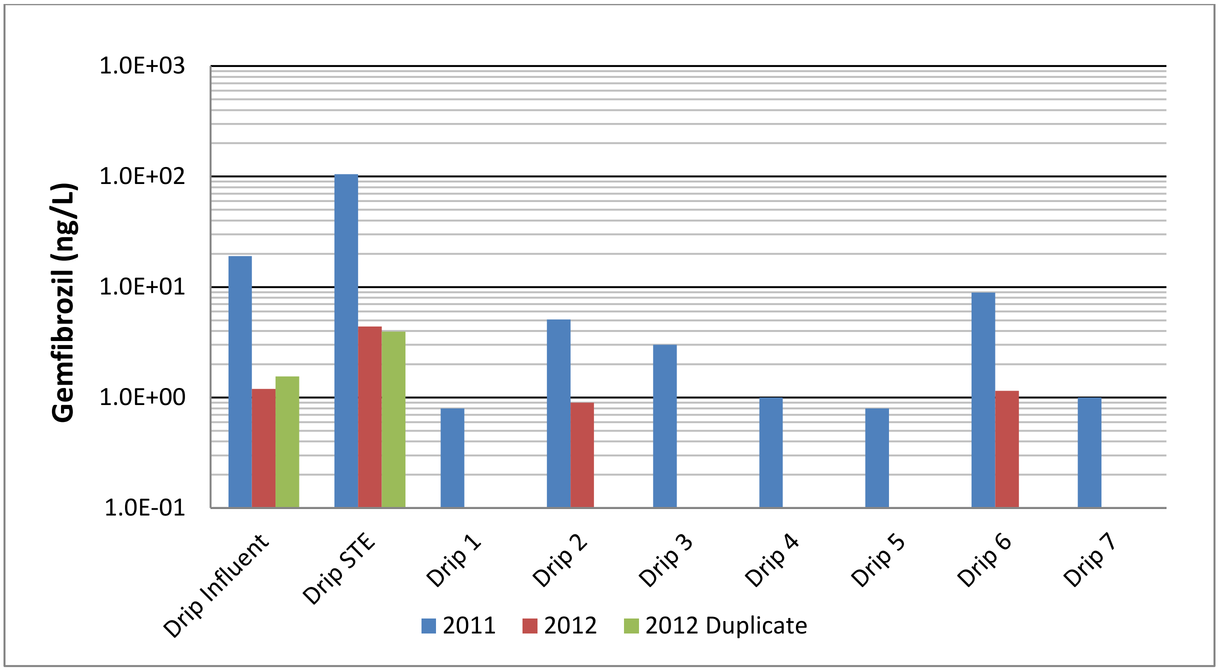

Figure 21. Concentration of gemfibrozil in samples taken 2011–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center. Drip 1 is a control (no wastewater); Drip 2–4 were not provided supplemental air; Drip 5–7 were supplemented with air as described above. STE = septic tank effluent.

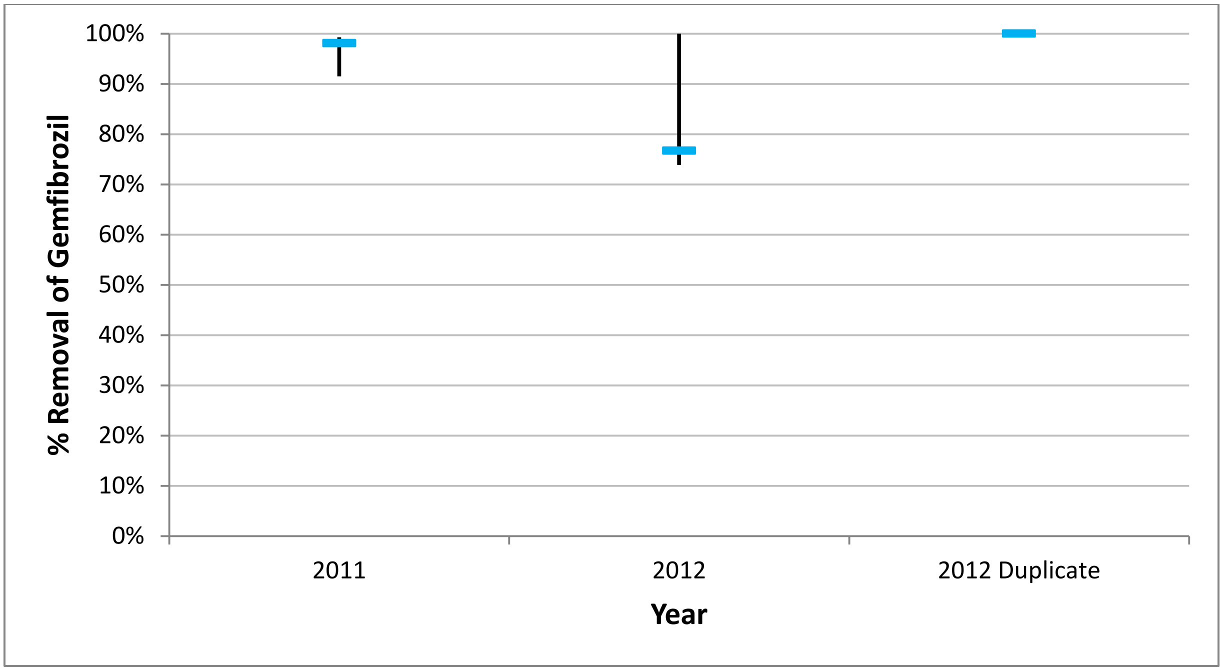

Figure 22. Percent removal of gemfibrozil in drip dispersal system as indicated by averaging percolate samples collected 2011–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center (median removal and range illustrated n=6 per year).

Sulfamethoxazole

Sulfamethoxazole is a sulfonamide antibiotic. Sulfonamides impede bacteria growth by inhibiting a metabolite necessary for the reproduction of DNA. Often used in conjunction with trimethoprim, sulfamethoxazole is perhaps the most common antibiotic found in wastewater. Further, sulfamethoxazole was one of the most common constituents found in drinking water wells on Cape Cod (Schaider et al. 2010). Results from samples taken in November 2010 (fig. 23) suggest that air enhancement increases treatment efficiency of the drip dispersal system (60–90 ng/L; 99.5% reduction) compared to no air enhancement (160–270 ng/L; 98.4% reduction). Results from samples taken in 2011 and 2012 however reveal no clear evidence of higher removals with air-enhancement. In general, >95% removal of sulfamethoxazole was observed in 2010–2012 (fig. 24).

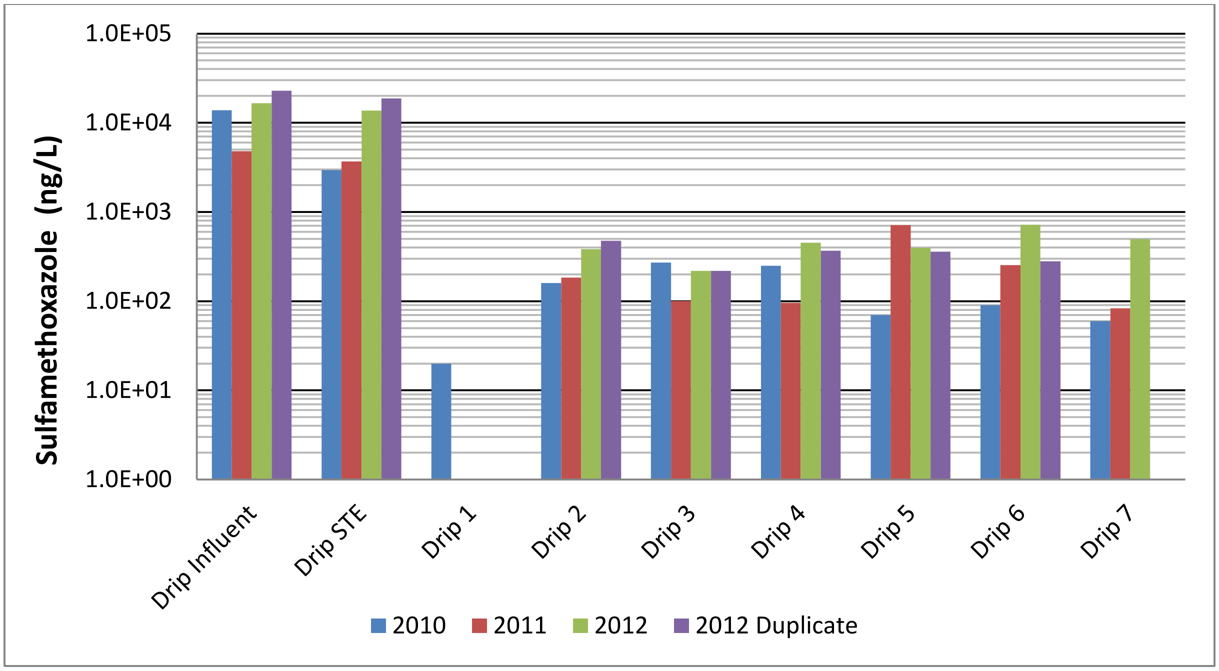

Figure 23. Concentration of sulfamethoxazole in samples taken 2010–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center. Drip 1 is a control (no wastewater); Drip 2–4 were not provided supplemental air; Drip 5–7 supplemented with air as described above. STE = septic tank effluent.

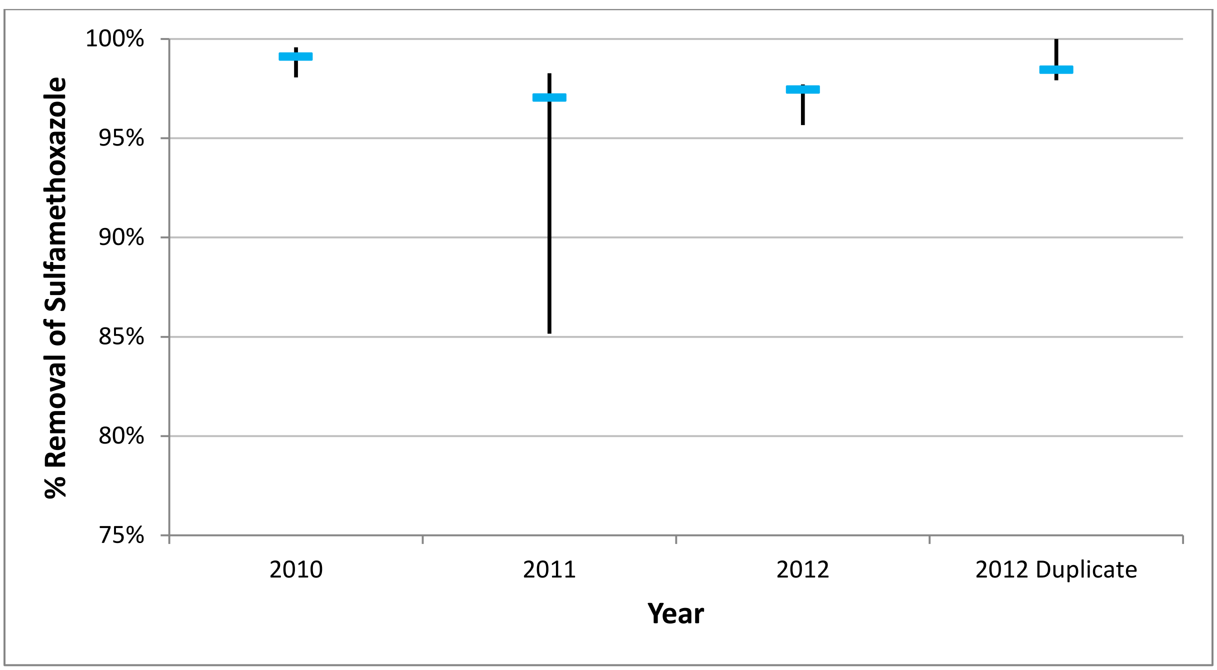

Figure 24. Percent removal of sulfamethoxazole in drip dispersal system as indicated by averaging percolate samples collected 2010–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center (median removal and range illustrated n=6 per year).

Miconazole

Miconazole is a topically applied fungicide. This compound was not detected in the first round of samples or in previous samples taken at the Test Center in 2004 (unpublished data). Samples taken in October 2011 suggest very little attenuation in the drip dispersal system (fig. 25); however, again, influent levels may be underestimated due to problems extracting the compound from the raw wastewater matrix.

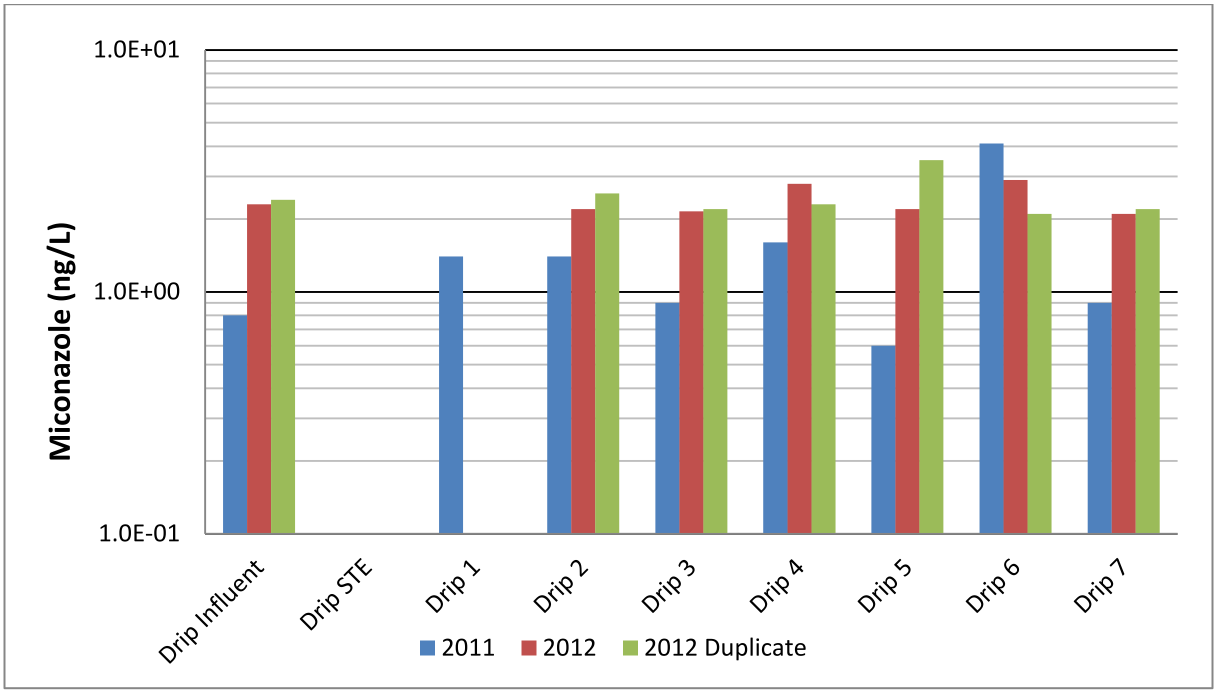

Figure 25. Concentration of miconazole samples taken in 2011–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center. Drip 1 is a control (no wastewater); Drip 2–4 were not provided supplemental air; Drip 5–7 were supplemented with air as described above. STE = septic tank effluent.

Cotinine

Cotinine is a metabolite of nicotine that has been suggested by some to be an indicator of wastewater influence. Data reported here suggest >99.5% removal in the drip dispersal system (fig. 26 & 27).

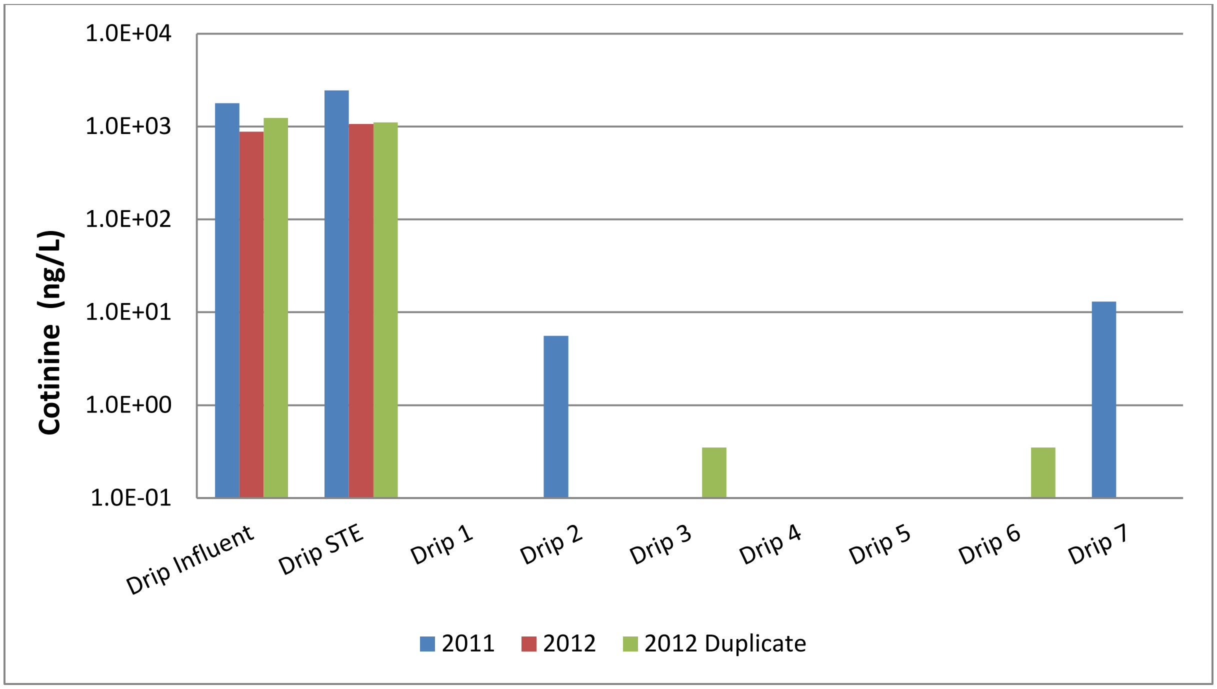

Figure 26. Concentration of cotinine samples taken 2011–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center. Drip 1 is a control (no wastewater); Drip 2–4 were not provided supplemental air; Drip 5–7 were supplemented with air as described above. STE = septic tank effluent.

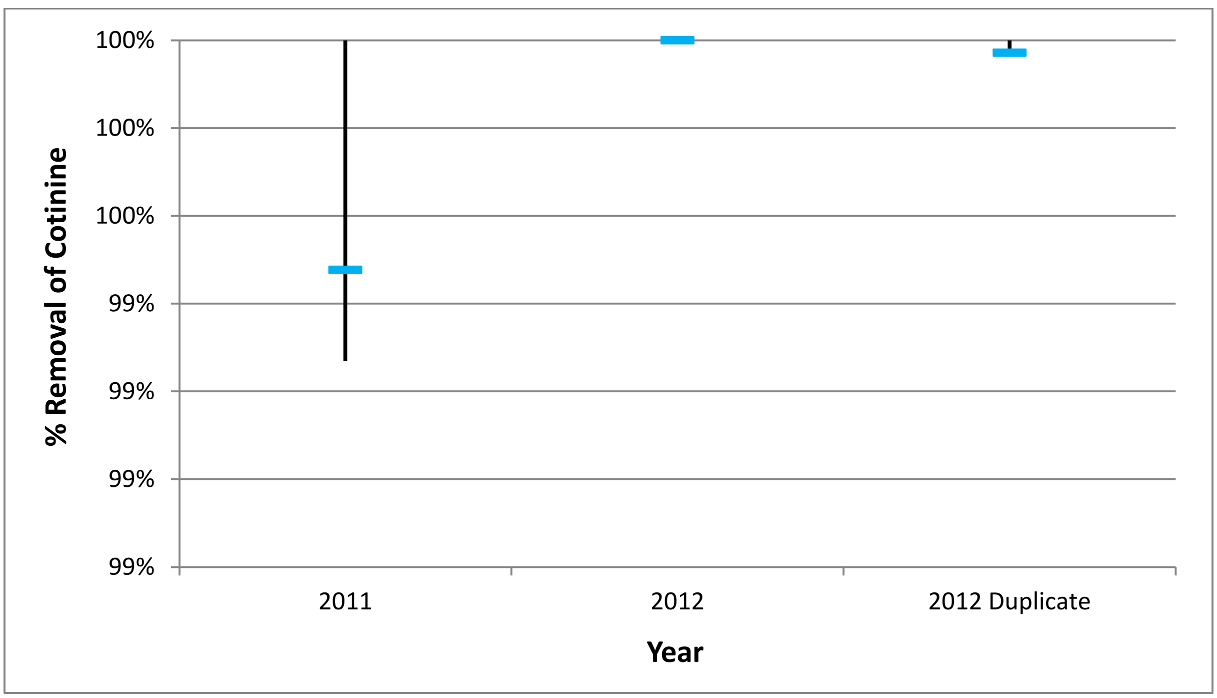

Figure 27. Percent removal of cotinine in drip dispersal system as indicated by averaging percolate samples collected 2011–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center (median removal and range illustrated n=6 per year).

Atorvastatin

Atorvastatin (Lipitor) is the most widely prescribed lipid regulator in the U.S. and Canada. Samples taken in November 2010 indicate a significantly lower concentration of atorvastatin in influent wastewater (~2 ng/L) than in October 2011 (~12 ng/L) and July 2012 (~42 - 46 ng/L). The effect of air enhancement in 2010 was inconclusive; however, the overall removal of atorvastatin in drip dispersal systems as indicated by sampling in 2011–2012 generally exceeds 90% (figs 28 & 29).

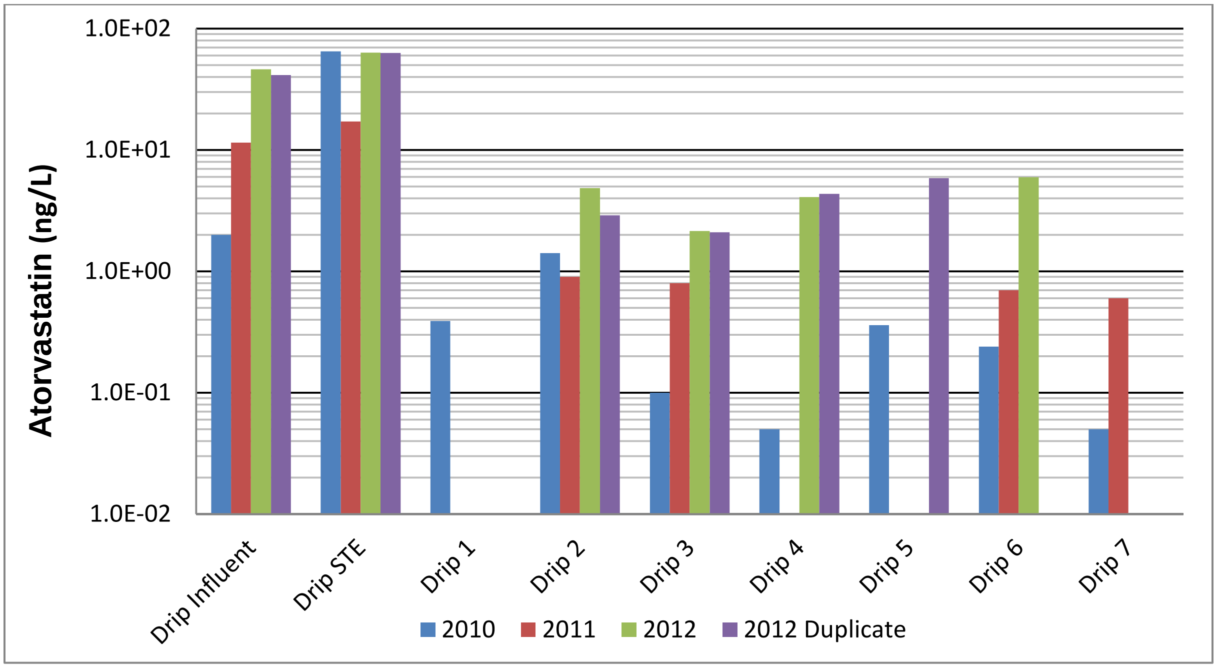

Figure 28. Concentration of atorvastatin in samples taken 2010–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center. Drip 1 is a control (no wastewater); Drip 2–4 were not provided supplemental air; Drip 5–7 supplemented with air as described above. STE = septic tank effluent.

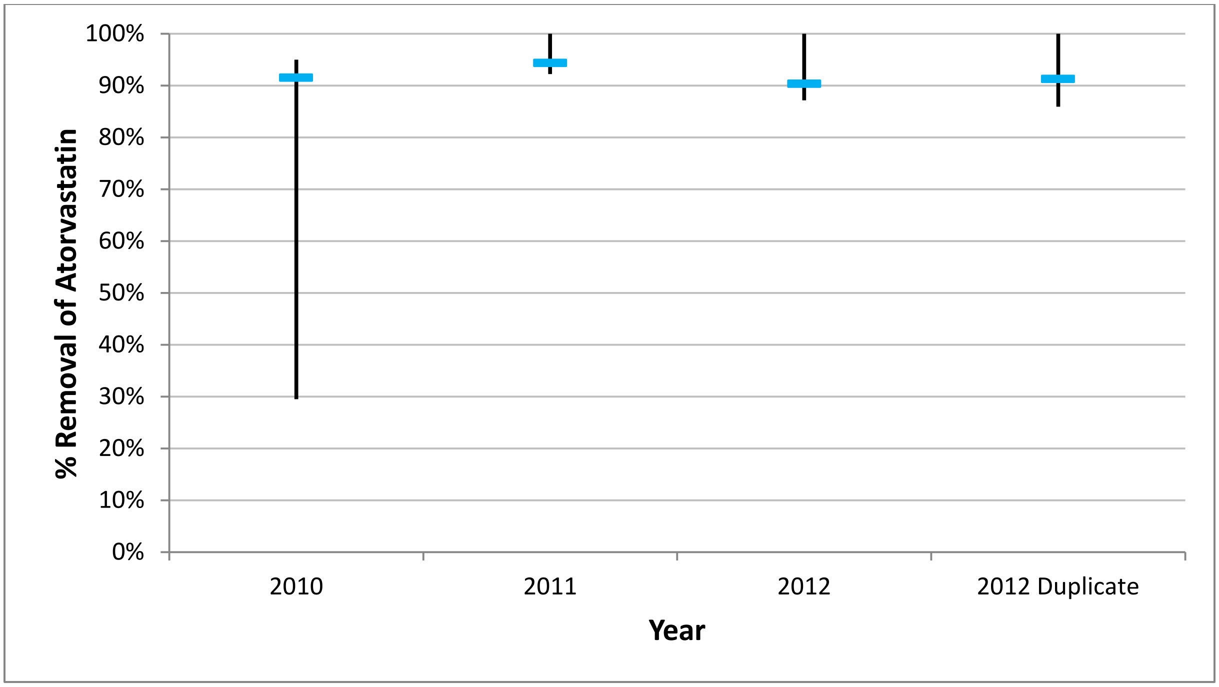

Figure 29. Percent removal of atorvastatin in drip dispersal system as indicated by averaging percolate samples collected 2011–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center (median removal and range illustrated n=6 per year).

Ciprofloxacin

Ciprofloxacin is a routinely prescribed antibiotic. It is commonly found in wastewater treatment plant effluent and surface waters influenced by these effluents (Guo et al. 2010). In the present study there is some indication that aerobic conditions are conducive to greater reduction of ciprofloxacin in soils-based systems (fig. 30); during the first round of samples in November 2010, ciprofloxacin was not observed in drip dispersal test cells supplemented with air. This trend did not persist however in samples taken in October 2011 and July 2012. The most recent samples in 2012 suggest an increasing treatment potential with time, as these duplicated samples show >95% removal despite a magnitude increase in the influent challenge (fig. 31). The presence of ciprofloxacin in the Drip 1 test cell on both sampling occasions (2010–2011) is unexplained; Drip 1 is not supplied with wastewater and is only continuous with treatment cells at elevations of >8” above the drip line.

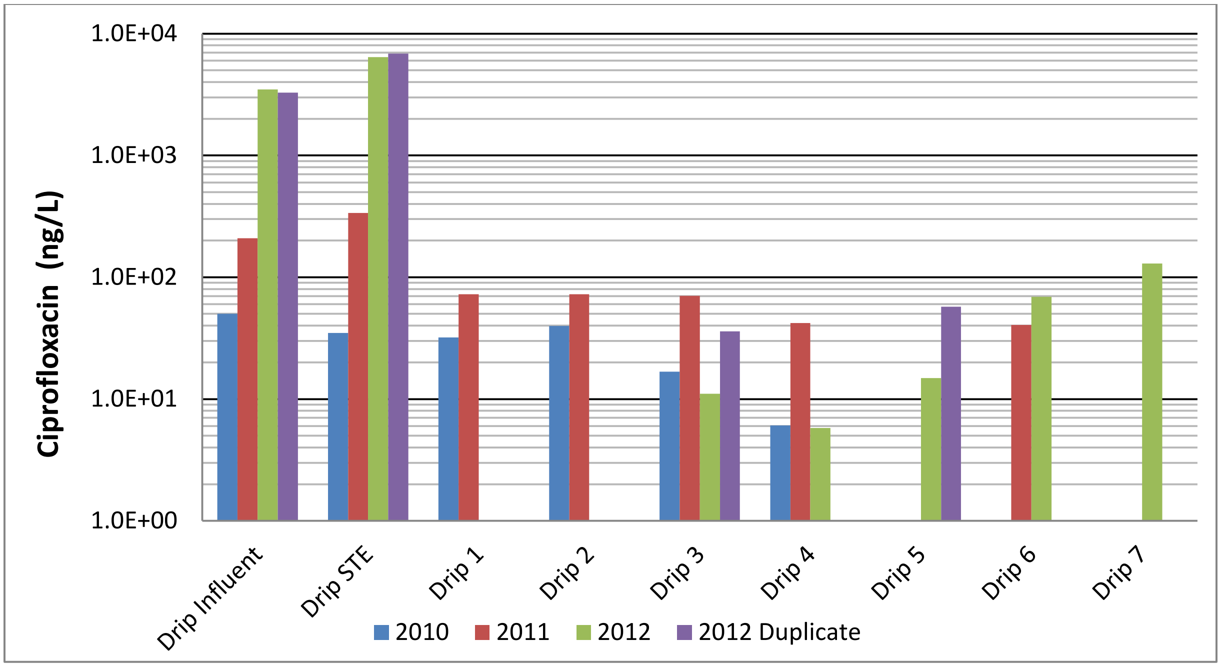

Figure 30. Concentration of ciprofloxacin in samples taken 2010–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center. Drip 1 is a control (no wastewater); Drip 2–4 were not provided supplemental air; Drip 5–7 supplemented with air as described above. STE = septic tank effluent.

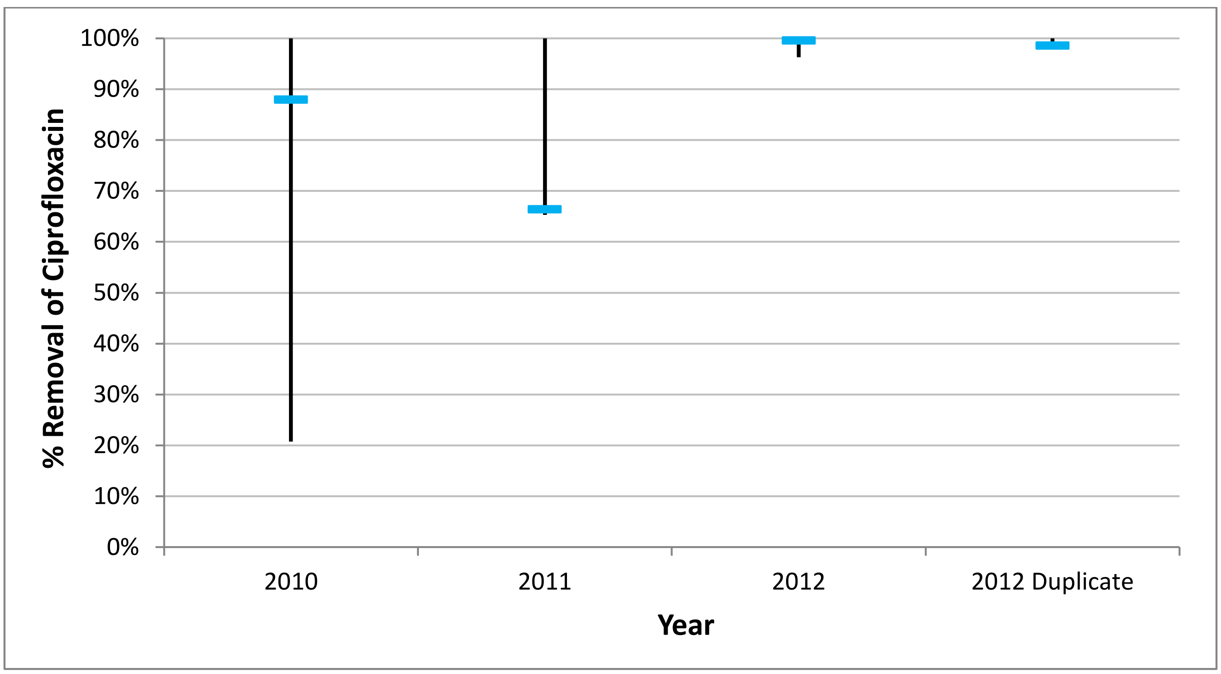

Figure 31. Percent removal of ciprofloxacin in drip dispersal system as indicated by averaging percolate samples collected 2010–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center (median removal and range illustrated n=6 per year).

Acetaminophen

Acetaminophen is a common non-prescription pain reliever. In October 2011, influent and septic tank effluent samples were found at concentrations of 1059 ng/L and 1693 ng/L respectively. It was not observed in any percolate samples beneath the drip dispersal system suggesting that the soils-based treatment is very effective in removing the compound. Samples taken in 2012 confirmed this by indicating >99% removal (fig. 32).

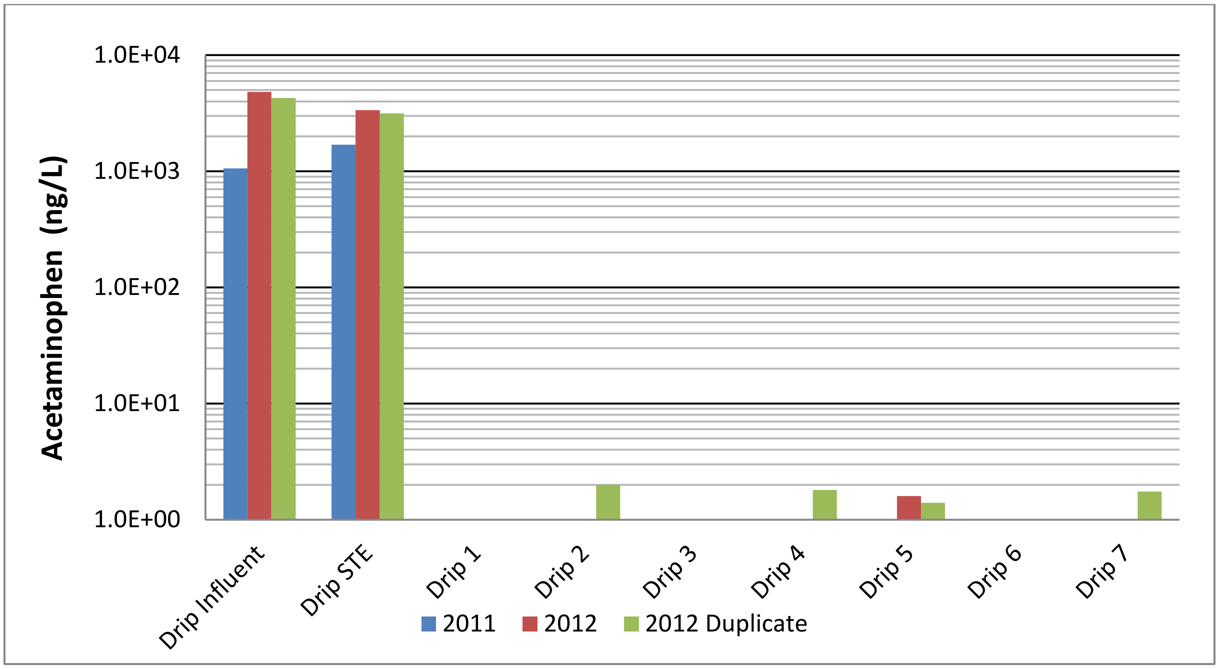

Figure 32. Concentration of acetaminophen in samples taken 2011–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center. Drip 1 is a control (no wastewater); Drip 2–4 were not provided supplemental air; Drip 5–7 supplemented with air as described above. STE = septic tank effluent.

Atenolol

Atenolol is a prescription beta-blocker used alone or in combination with other medications to treat high blood pressure. It works by relaxing blood vessels and slowing heart rate to improve blood flow and decrease blood pressure. Assayed in October 2011 and July 2012 only, removal rates in the drip dispersal system were generally greater than 90% (figs. 33 & 34).

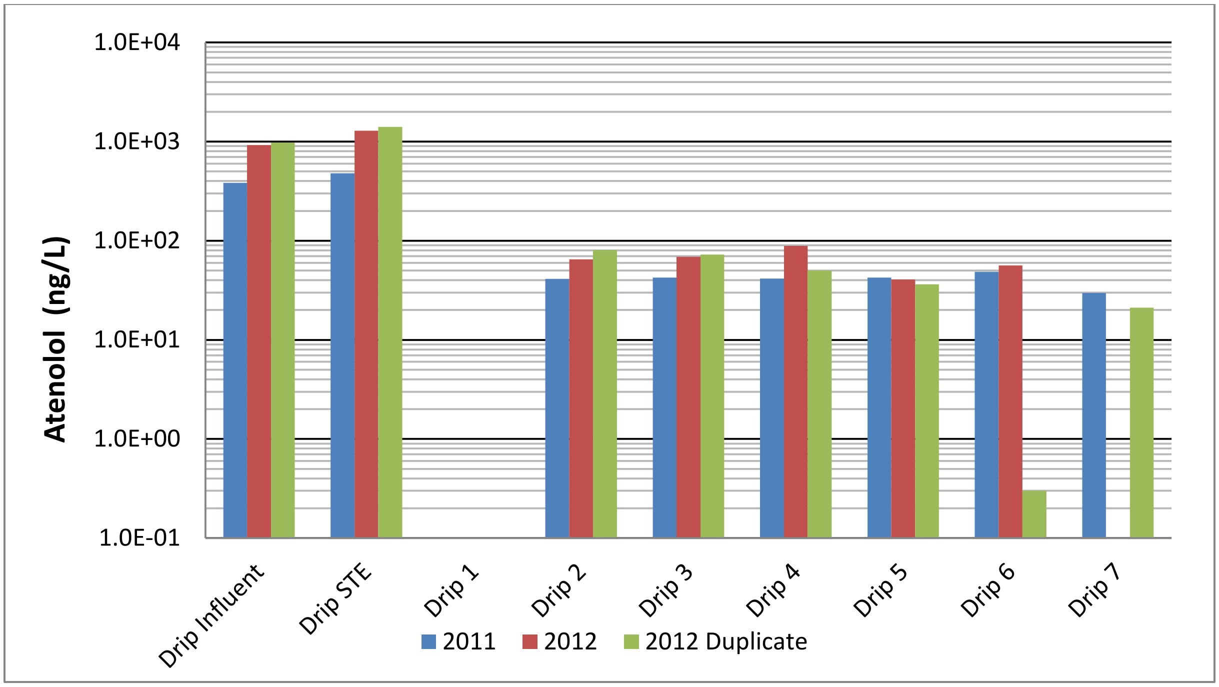

Figure 33. Concentration of atenolol in samples taken 2011–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center. Drip 1 is a control (no wastewater); Drip 2–4 were not provided supplemental air; Drip 5–7 were supplemented with air as described above. STE = septic tank effluent.

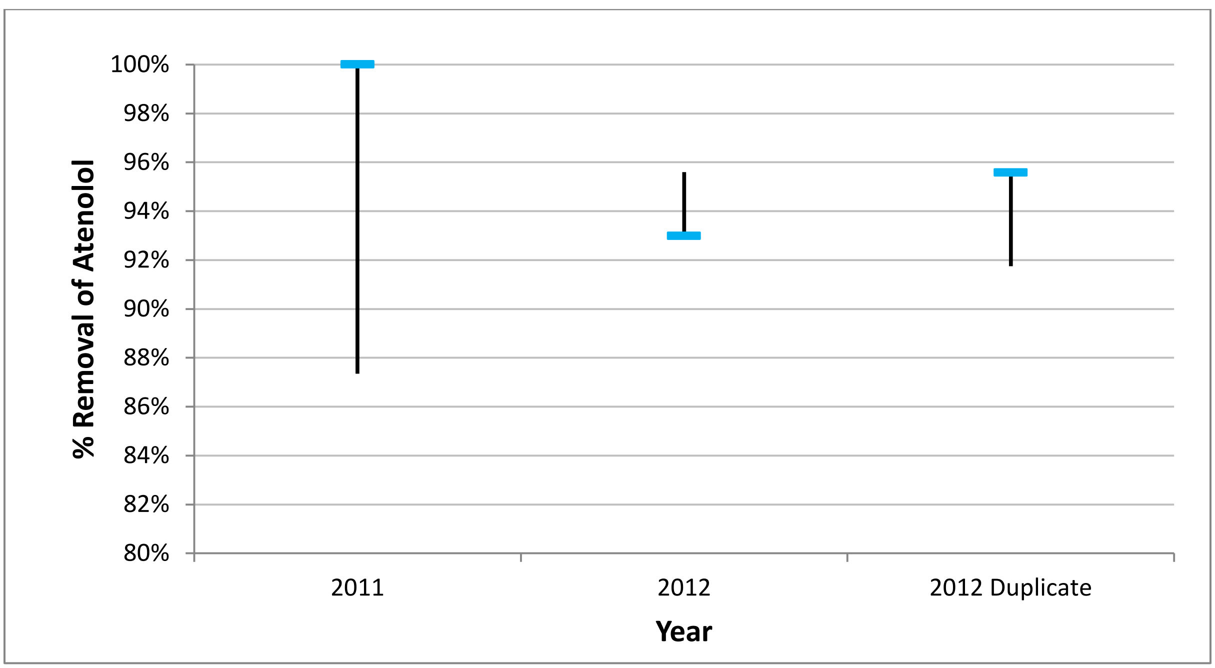

Figure 34. Percent removal of atenolol in drip dispersal system as indicated by averaging percolate samples collected 2011–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center (median removal and range illustrated n=6 per year).

Diclofenac

Diclofenac is a non-steroidal anti-inflammatory drug used to reduce swelling caused by arthritic conditions. Samples taken in October 2011 and July 2012 suggest removals approaching 90% in the drip dispersal system with a notable exception that occurred in Drip 7 in 2011 (figs. 35 and 36). Removal efficiencies reported here are greater than those reported in a summary of selected wastewater treatment plants (Schröder 2010).

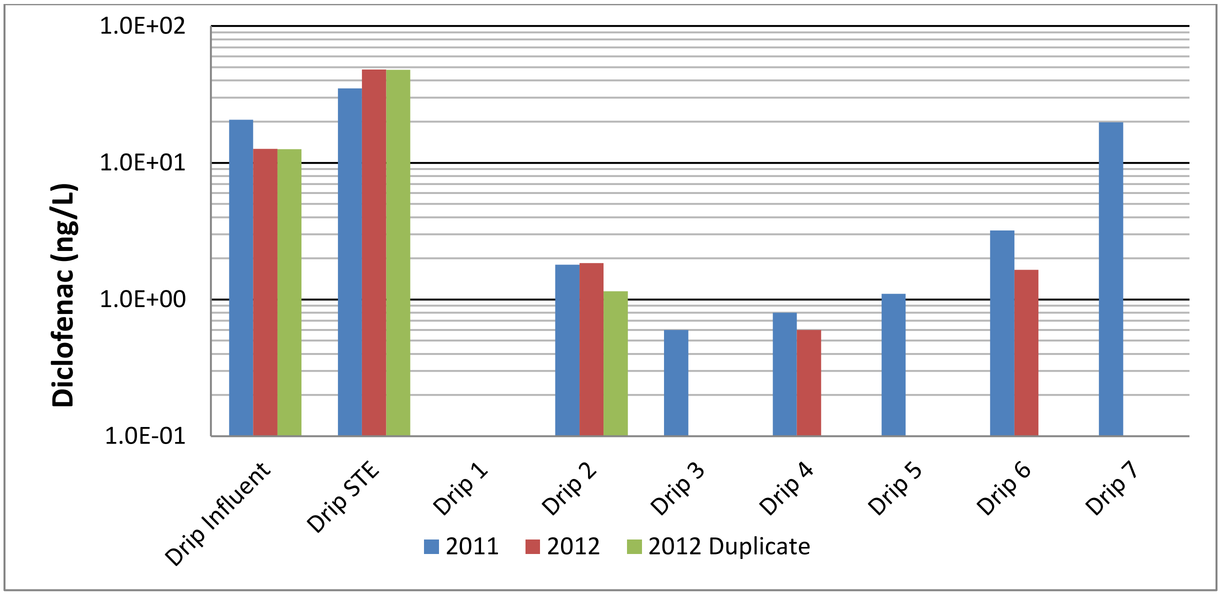

Figure 35. Concentration of diclofenac samples taken 2011–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center. Drip 1 is a control (no wastewater); Drip 2–4 were not provided supplemental air; Drip 5–7 were supplemented with air as described above. STE = septic tank effluent.

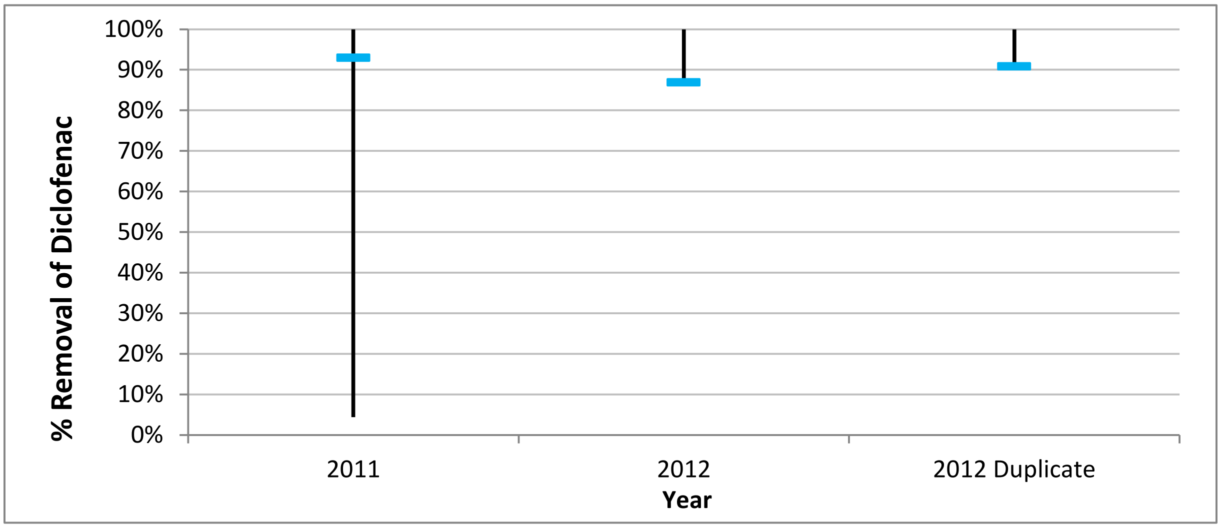

Figure 36. Percent removal of diclofenac in drip dispersal system as indicated by averaging percolate samples collected 2011–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center (median removal and range illustrated n=6 per year).

Doxorubicin

Doxorubicin is administered intravenously in the treatment of a wide range of cancers. In October 2011 it was found at levels approximating 6 ng/L in the influent and septic tank effluent, however, it was not detected in any percolate samples. Therefore, the data suggest efficient removal of doxorubicin in soils-based systems. Subsequent sampling in 2012 indicated the absence of doxorubicin in the influent, but percolate sampling results yielded values ranging from non-detect – 3.5 ng/L (mean 2.0 ng/L and median 1.7 ng/L). The absence of doxorubicin in influent concurrent with its presence in percolate samples may suggest either matrix-analyses problems or a high variability in the concentration of the influent.

Ibuprofen

Ibuprofen is a commonly used non-prescription pain reliever. Assayed in 2011 and 2012, the data suggest >99% removal in drip dispersal systems (fig. 37). Removal efficiencies reported here are similar to those reported for various wastewater treatment technologies (Schröder 2010).

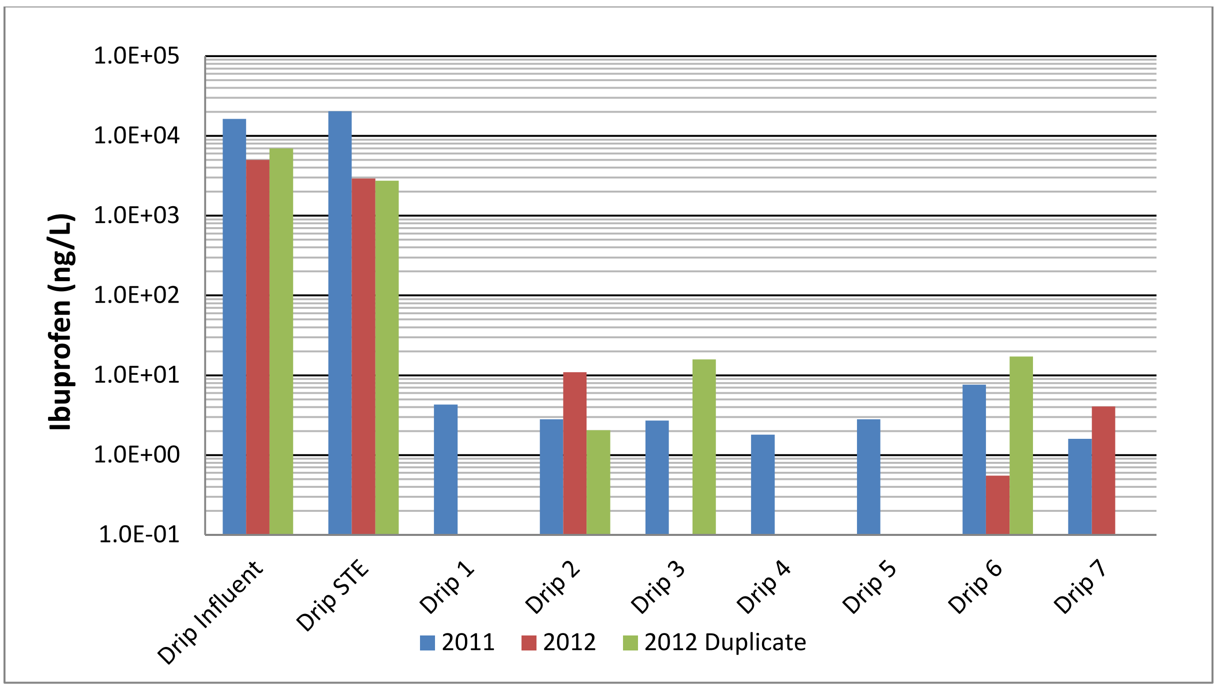

Figure 37. Concentration of ibuprofen samples taken 2011–2012 at the drip dispersal system of the Massachusetts Alternative Septic System Test Center. Drip 1 is a control (no wastewater); Drip 2–4 were not provided supplemental air; Drip 5–7 were supplemented with air as described above. STE = septic tank effluent.

Summary

We report here that removal efficiencies of selected pharmaceuticals, hormones and personal care products in drip dispersal systems are generally higher than those levels reported for non-soils-based treatment technologies. Many removal efficiencies of the selected compounds using drip dispersal reported herein approach 100% (fig. 38).

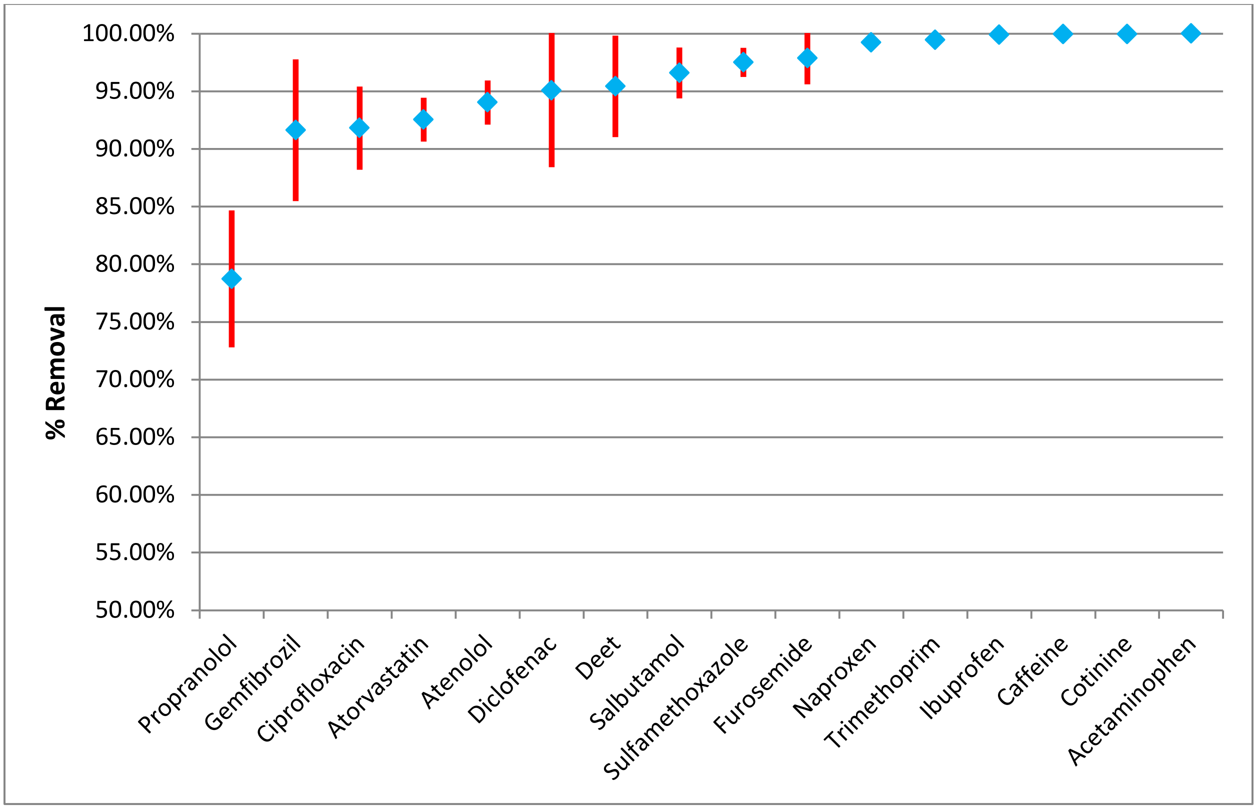

Figure 38. Summary of removal efficiencies of drip dispersal septic systems for selected micro-constituents of wastewater.

The data suggest that septic systems employing shallow soils-based means for ultimate disposal may offer comparable to better treatment for certain micro-constituents of wastewater compared to some municipal wastewater treatment facilities. To illustrate this, results from this study and selected studies of large treatment plants are presented in table 2.

Compound	Drip Dispersal System	Activated Sludge with Six Lagoons$_b$	Two Oxidation Ditches$_b$	3 Bioreactors with UV$_b$	10 Lagoons in Series$_b$	WWTP Trickling Filters$_a$	WWTP Activated sludge$_a$	Onsite Sand Filter$_c$	Vertical Flow Constructed Wetland$_c$	Activated sludge Treatment$_d$	Summarization of Various Technologies$_e$	Seven Wastewater Treatment Plants$_f$	Four WWTP (Secondary Treatment) in China$_g$
Acetaminophen	99.8-99.9%										92-100%		
Atenolol	89-99%									14%		20-97%	
Atorvastatin	91-94%											40-80%	
Caffeine	99.9-100%	98%	97%	96%	98%			68± 27%	99±1%	95%			
Ciprofloxacin	88-95%									57%		37-99%	
Cotinine	99.9-100%												
DEET	91-100%												73-90%
Diclofenac	89-100%	95%	94%	61%	90%	0-35%	0-45%	82%		5%	0-69%		30-50%
Furosemide	96-100%												
Gemfibrozil	86-97%	78%	90%	72%	15%					76%	16-69%	30-99%	
Ibuprofen	99%	99%	89%	96%	77%	85-95%	95-99%	86±23%		95%	0-100%		
Naproxen	99-100%	98%	90%	98%	90%	58-68%	78-95%	65±40%		61%	0-90%		
Propanolol	73-85%					0-97%				< 20%	96%		
Ranitidine	>95%									31%		50-98%	
Salbutamol	95-99%											20-99%	
Sulfamethoxazole	96-99%					0-65%	75-98%			17%	20-100%	30-92%	
Trimethoprim	99-100%					40-60%	75-80 %				3-100%		65-100%

Table 2. Comparison of removal efficiencies between drip dispersal systems and large treatment plants. a.Ying, Kookana, and Kolpin 2009, b. Kasprzyk-Hordern, Dinsdale, and Guwy 2009, c. Matamoros et al. 2009, d. Rosal et al. 2010, e. Schröder 2010, f. Gros et al. 2010.

We report that certain compounds, notably the fire retardant TCEP, appear recalcitrant in soils-based treatment indicating little, if any, removal. Due to analytical difficulties, the removal efficiencies of certain other compounds such as warfarin, miconazole, doxorubicin and ranitidine could not be determined with any degree of confidence.

It should be stressed here that this study is considered preliminary and of a broad survey character. Over the coming months, we hope to duplicate some of the work conducted herein and focus particularly on the role of air enhancement in the improvement of removal efficiency for the compounds discussed. As previously mentioned, some technical difficulties prevented the clarification of oxygen's role in the soil's treatment process. Nevertheless, these data do suggest the efficacy of shallow soils-based treatment system for removing selected micro-constituents of wastewater.

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Appendix 1

Raw Data

Special Environmental Analysis
Program

A Joint Effort Between the
Environmental Analysis Laboratory (EAL) and the
UMass Environmental & Water Resources Engineering Program

Sample Results: November 2010

	Sulfamethoxazole ng/l	Ciprofloxacin ng/L	TCEP ng/L	Trimethoprim ng/L	Caffeine pg/L	DEET ng/L	Atorvastatin ng/L	Naproxen ng/L	Propanolol ng/L	Diphenhydramine ng/L	Metformin ng/L
Drip Influent	13880	50.17	12.46	385.61	20090	7.93	2.00	6870	3.83	31.8	123.3
Drip STE	2950	34.89	8.02	26.3	5296.44	116.45	0.65	310	0.39	28.1	20.33
Drip #1	20	32.06	0	0	9.25	0.19	0.39	850	0.46	0	0
Drip #2	160	39.76	9.43	0	4.54	4.66	1.41	530	0.12	0	0
Drip #3	270	16.73	7.04	0	4.91	3.56	0.10	270	0.27	0	0
Drip #4	250	6.06	3.04	0	6.12	5.74	0.05	90	0.12	0	0
Drip #5	70	0	2.87	0	28.05	13.63	0.36	90	0.31	0	0
Drip #6	90	0	7.32	0	34	43.34	0.24	120	0.54	0	0
Drip #7	60	0	4.91	0	23.03	41.43	0.05	70	0.09	0	0

Sample Results: October 2011

Barnstable County Department
of Health and Environment
PPCP EDC & Cytotoxin Removal
10/11/2011 Sampling

IS = INTERNAL STANDARD CALIBRATION
using labeled analog
ES = EXTERNAL STANDARD CALIBRATION
ES* = ES using method standards
Empty cells are below detection limit

		Acetaminophen	Atenolol	Atorvastatin	Caffeine	Cimetidine	Ciprofloxacin	Cotinine	DEET	Diclofenac	Diltiazem	Diphenhydramine	Doxorubicin
	Ion mode	+	+	+	+	+	+	+	+	+	+	+	+
	Calibration	ES	IS	IS	ES*	ES	ES*	ES*		ES	ES*	ES*	ES
Sample Name	**Notes**												
Drip Influent	***Units are ng/l***	1059.40	382.70	11.30	54062.02		209.37	1777.82	1396.01	20.70	235.34	189.74	6.40
Drip STE		1693.20	480.60	17.20	18762.31	5.00	336.28	2447.62	1081.94	35.10	499.23	113.88	6.10
Drip 1					28.53		72.74				21.04		
Drip 2			41.20	0.90	14.80			5.60	3.70	1.80	26.29		
Drip 3			42.40	0.80			70.30		4.68	0.60	199.65		
Drip 4			41.60				41.98		3.71	0.80	15.97		
Drip 5			42.40						8.61	1.10	8.95		
Drip 6			48.40	0.70		9.60	40.46		27.33	3.20	89.38		
Drip 7			29.70	0.60				12.99	2.75	19.80			
0 µg/L	Method Standard						0.08		1.16		2.69		
6.25 µg/L	Method Standard		0.70	2.60	0.74		0.38	4.57	6.44		16.82	4.63	2.80
12.5 µg/L	Method Standard	0.60	2.30	3.90	18.46		12.33	11.91	8.51		8.07	12.61	2.80
25 µg/L	Method Standard		4.30	6.50	72.51		25.08	33.39	24.00		555.86	26.69	
50 µg/L	Method Standard		12.50	18.10	49.90		14.07	50.88	55.81		32.57	58.02	2.90
100 µg/L	Method Standard		26.30	36.20	99.65		47.24	97.64	97.83		108.61	95.66	3.10
	Percent Recovery (*m* M / *m* ES) * 100			10%	40%		4%	27%	72%		92%	41%	

		Estradiol	Estrone	Furosemide	Gemfibrozil	Ibuprofen	Miconazole	Naproxen	Propranolol	Ranitidine	Salbutamol	Sulfamethoxazole	TCEP	Trimethoprim	Warfarin
	Ion mode	-	-	-	-	-	+	-	+	+	+	+	+	+	-
	Calibration	ES *	ES	ES*	ES*	ES	ES*	IS	IS	IS	ES*	IS	ES*	IS	ES*
Sample Name	**Notes**														
Drip Influent	***Units are ng/l***	65.63	2.00	138.15	18.96	16355.00	0.84	7233.20	10.60	165.90	38.13	4799.70	25.95	584.10	
Drip STE		41.00	3.10	59.86	104.87	20406.70	0.11	7844.90	26.40	60.40	40.49	3696.60	40.32	260.10	
Drip 1		33.81		0.84	0.76	4.30	1.42								
Drip 2		17.51	3.30	0.21	5.11	2.80	1.38	4.30	7.00			183.60	78.23	1.60	4.99
Drip 3		9.27		0.27	3.05	2.70	0.91	1.30	7.10	0.70		100.50	98.82	3.00	9.30
Drip 4		15.94	2.20	0.29	1.02	1.80	1.57	2.10	6.80	0.20		95.40	81.83	3.10	3.85
Drip 5			1.80	1.74	0.80	2.80	0.61	1.90	8.70			712.60	90.86	4.40	5.32
Drip 6			2.30	11.59	8.89	7.60	4.08	34.10	12.80			252.90	85.51	5.00	1.82
Drip 7				1.08	1.03	1.60	0.90	1.30	6.30			83.50	70.85	3.20	2.05
0 µg/L	Method Standard			0.60	0.43	0.80	0.65	0.10					1.93		
6.25 µg/L	Method Standard	4.68	10.60	6.58	6.63	1.10	7.68	4.50	4.20		9.04	1.20	5.58	1.80	5.76
12.5 µg/L	Method Standard	9.72	16.30	11.12	11.35	9.10	12.29	21.90	6.00	7.70	13.92	5.10	10.20	3.60	11.62
25 µg/L	Method Standard	34.67	33.40	25.59	24.52	0.60	25.37	31.60	10.10		24.96	7.90	26.22	8.10	27.83
50 µg/L	Method Standard	43.29	66.60	49.69	51.16	0.80	45.84	53.70	21.90	32.60	42.33	24.30	49.62	17.40	48.20
100 µg/L	Method Standard	101.38	114.10	100.16	99.66	0.70	101.93	126.20	37.90	46.50	103.49	39.90	100.22	31.90	100.33
	Percent Recovery (*m* M / *m* ES) * 100	56%	112%	52%	36%		36%	121%	47%	58%	47%	36%	80%	59%	49%

Sample Results: July 2012

Barnestable County Department of Health and Environment	**IS = INTERNAL STANDARD CALIBRATION using labeled analog**													
PPCP EDC & Cytotoxin Removal 07/2012 Sampling	**ES = EXTERNAL STANDARD CALIBRATION using method standards Empty cells are below detection limit**													
		Acetaminophen	**Atenolol**	**Atorvastatin**	**Caffeine**	**Ciprofloxacin**	**Cotinine**	**DEET**	**Diclofenac**	**Diphenhydramine**	**Doxorubicin**	**Estradiol**	**Estrone**	
	Ion mode	+	+	+	+	+	+	+	+	+	+	-	-	
	Calibration	ES	IS	IS	ES	ES	ES		ES	ES	ES	ES	ES	
Sample Name	**Notes**													
Influent (1 of 2)	***Units are ng/L***	4811.70	924.80	46.30	15494.85	3482.68	879.90	1495.65	12.65	150.04		10.95	27.65	
Influent (2 of 2)		4269.30	976.60	41.50	17151.65	3273.52	1232.75	1681.10	12.60	168.15		16.20	26.25	
DRIP STE (1 of 2)		3362.35	1286.40	63.35	3960.10	6426.73	1065.05	1779.10	48.20	147.06			17.90	
DRIP STE (2 of 2)		3159.85	1403.85	62.90	4722.45	6867.12	1106.90	1800.15	47.85	150.29		2.90	23.15	
DRIP 2 (1 of 2)			64.90	4.85	4.15			32.45	1.85		1.55	10.00	3.60	
DRIP 2 (2 of 2)		2.00	80.60	2.90	0.35			0.45	1.15			3.55	1.85	
DRIP 3 (1 of 2)			68.70	2.15	3.85	11.05		7.50			3.50	7.60	2.85	
DRIP 3 (2 of 2)			72.50	2.10	10.10	35.90	0.35	14.85			2.20	4.50	4.20	
DRIP 4 (1 of 2)			88.95	4.10	0.65	5.80		9.90	0.60		1.50	6.60	4.15	
DRIP 4 (2 of 2)		1.80	49.95	4.35	3.85			12.55			1.15	6.35	4.85	
DRIP 5 (1 of 2)		1.60	40.70		1.05	14.85		6.75			0.95		2.90	
DRIP 5 (2 of 2)		1.40	36.30	5.85	3.45	57.40		10.20					2.70	
DRIP 6 (1 of 2)			56.35	5.95	7.85	69.00		34.30	1.65			7.40	5.65	
DRIP 6 (2 of 2)			0.30		8.15		0.35	8.25					3.75	
DRIP 7 (1 of 2)						129.35					1.75		4.05	
DRIP7 (2 of 2)		1.75	21.05		1.70			18.05			3.35	9.75	3.65	
TRIP BLANK (1 of 2)		1.45		2.15		9.10		13.05			9.70			
TRIP BLANK (2 of 2)		4.60	9.15			6.55					1.00	1.70	0.50	
0 ng/L	Method Standard		14.60	3.20	1.95			0.20		10.05	2.00		1.15	
12.5 ng/L	Method Standard	13.10	3.95	9.10	9.60	10.10	12.60	13.10	12.65	4.75	8.40	12.50	11.50	
50 ng/L	Method Standard	39.70	45.25	42.80	58.75	64.15	52.00	57.95	57.50	54.35	60.35	48.25	49.50	
400 ng/L	Method Standard	433.50	404.20	393.40	377.40	376.00	391.65	389.30	414.20	363.00	336.50	368.90	371.40	
800 ng/L	Method Standard	776.25	809.10	817.20	816.70	812.30	806.25	802.20	778.15	840.40	857.25	832.85	830.10	
	Percent Recovery	42%	90%	14%	69%	2%	71%	58%	84%	86%		45%	41%	

		Furosemide	**Gemfibrozil**	**Ibuprofen**	**Miconazole**	**Naproxen**	**Primidone**	**Propranolol**	**Ranitidine**	**Salbutamol**	**Sulfamethoxazole**	**TCEP**	**Trimethoprim**	**Warfarin**
	Ion mode	-	-	-	+	-	+	+	+	+	+	+	+	-
	Calibration	ES	ES	ES	ES	IS	IS	IS	IS	ES	IS	ES	IS	ES
Sample Name	**Notes**													
Influent (1 of 2)	***Units are ng/L***	15.45	1.20	4986.45	2.30	20266.85	0.25	161.11	100.15	14.45	16613.55	13.45	2186.60	
Influent (2 of 2)		15.55	1.55	7005.25	2.40	20781.80		146.83	71.75	16.65	22798.45	17.75	2321.35	
DRIP STE (1 of 2)		7.80	4.40	2940.60		18371.40	1.05	160.51	82.30	25.70	13661.00	26.95	609.95	
DRIP STE (2 of 2)		8.20	3.95	2745.65		17652.65	2.45	158.56	40.25	25.70	18755.00	26.80	682.60	
DRIP 2 (1 of 2)		0.05	0.90	10.90	2.20	62.00	18.35	46.30		1.35	382.00	107.15	12.35	1.25
DRIP 2 (2 of 2)				2.05	2.55	78.50	0.05	51.60	195.20	1.95	475.00	6.40	45.95	
DRIP 3 (1 of 2)					2.15		1.80	47.10		0.45	219.40	81.35	13.60	
DRIP 3 (2 of 2)				15.80	2.20	2.15	15.90	47.95		0.45	218.20	114.30	11.90	3.90
DRIP 4 (1 of 2)		0.25			2.80	4.05	16.45	60.15		2.75	453.00	101.65	24.80	7.30
DRIP 4 (2 of 2)					2.30	3.20	14.20	44.70			367.40	107.85	10.75	5.00
DRIP 5 (1 of 2)					2.20	1.50	2.95	48.95		0.55	397.15	84.20	14.20	
DRIP 5 (2 of 2)		0.05			3.50	0.95	14.10	47.10		0.45	357.55	105.55	14.35	2.40
DRIP 6 (1 of 2)		0.20	1.15	0.55	2.90	34.05	12.35	55.25			721.55	115.15	23.75	5.10
DRIP 6 (2 of 2)		0.15		17.25	2.10		14.45	0.95		0.45	279.30	94.35	2.85	
DRIP 7 (1 of 2)				4.05	2.10	0.05			131.45	0.45			34.30	0.45
DRIP7 (2 of 2)		0.35		0.10	2.20		5.30	33.55		0.50	497.10	112.90	8.65	
TRIP BLANK (1 of 2)					2.10					0.95				
TRIP BLANK (2 of 2)				1.75	2.10	69.65		3.00		0.90	110.75		29.50	
0 ng/L	Method Standard		1.65	0.60	2.40	1.55	2.30	1.10		1.00	6.75	1.25	3.55	
12.5 ng/L	Method Standard	12.35	11.90	11.90	14.60	11.00	9.65	11.80	51.45	8.55	8.20	13.05	9.15	11.45
50 ng/L	Method Standard	53.25	44.10	54.90	30.30	53.65	56.20	50.30		63.25	48.80	55.45	56.35	57.05
400 ng/L	Method Standard	403.75	448.80	394.95	347.30	395.25	421.35	402.45	486.35	358.95	397.60	400.30	400.55	446.10
800 ng/L	Method Standard	793.10	757.75	800.65	870.25	802.65	775.35	798.00	112.75	831.65	807.95	793.70	796.50	747.95
	Percent Recovery	49%	72%	70%	30%	169%	101%	101%	9%	63%	51%	75%	53%	89%