White Paper

Contaminants of Emerging Concern

from Onsite Septic Systems

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Executive Summary

Many rural areas of the United States continue to rely on onsite septic systems as a permanent means of wastewater treatment and disposal. This is also the case in Barnstable County (Cape Cod) which is designated by EPA as having a sole-source aquifer and where over 80% of the wastewater treatment is performed by onsite septic systems. To assess the implications of onsite wastewater disposal in this area where septic systems are hydraulically connected with drinking water sources and aquatic habitats, we have compiled information on the state of our understanding relative to the impact of certain contaminants of emerging concern (CEC) that originate in wastewater. These include pharmaceuticals (antibiotics, hormone therapies, cancer therapies, etc.), personal care products (deodorants, shampoos, insect repellants, etc) and certain by-products of manufactured products (phenolic surfactants, fire retardants, etc).

Studies conducted on Cape Cod and elsewhere confirm the potential for impacts to human health and the environment related to CEC. We review three aspects of CEC and onsite wastewater treatment/disposal that we propose are of highest priority: endocrine disruption by selected CEC, the effect of antibiotic pharmaceuticals, and direct toxic effects of selected CEC. The rationale for prioritizing concerns in this manner is discussed.

Finally, we review available studies regarding onsite septic system technologies, including advanced treatment. We suggest design changes to standard soil absorption systems that several of the published studies reviewed herein suggest would improve performance for the removal of CEC. The authors concede that further research is necessary to validate the efficacy of these recommendations.

Introduction

By its nature, wastewater disposal presents a route for the various constituents of wastewater to the environment at large. While the ultimate goal of wastewater treatment is to reduce all elements of wastewater to innocuous substances, it is clear throughout the history of wastewater treatment that this goal is rarely achieved. Medical and technological advances over past decades have resulted in the increased introduction of a wide range of new and complex chemicals into domestic wastewater, which further challenges basic wastewater treatment goals. Ranging from pharmaceuticals and personal care products to natural byproducts (caffeine, estrogen-like compounds) and by-products of processes used to treat or manufacture household items (fire retardants, plasticizers, etc.), there has been increasing concern regarding possible consequences of the release of these compounds to the environment at large during the wastewater treatment and disposal process. As a result, the fate and transport of these compounds collectively referred to herein as Contaminants of Emerging Concern (CEC), has been the subject of increasing study.

Studies that document septic systems as sources of CEC to groundwater (Schaider et al. 2010; Standley et al. 2008; Singh et al. 2010; Benotti et al. 2006; Rosen and Kropf 2009; Carrara et al. 2008; Godfrey, Woessner, and Benotti 2007; Katz et al. 2010; Zimmerman 2005; Swartz et al. 2006) raise particular concern on Cape Cod where over 80% of households are served by septic systems. Cape Cod's designation as a sole source aquifer means that all drinking water sources are part of a contiguous groundwater supply that hydraulically connects wastewater discharge sites to drinking water sources. Furthermore, most freshwater ponds, lakes and streams are a surface expression of groundwater, and estuaries receive inputs from groundwater as it exits the freshwater system. This particular feature raises concern due to the abundant evidence that trace levels of certain CEC can have substantial effects on wildlife (Segner et al. 2003; Blazer et al. 2011; Ying, Kookana, and Ru 2002; Ankley et al. 2007; Nash et al. 2004; Campbell et al. 2006; Crane, Watts, and Boucard 2006; Soin and Smagghe 2007; Colborn, vom Saal, and Soto 1993; DeLorenzo and Fleming 2008; Kasprzyk-Hordern, Dinsdale, and

Guwy 2008; Kidd et al. 2007; Luckenbach, Corsi, and Epel 2004; Luckenbach and Epel 2005).

The issue of CEC release to the environment is daunting. Analytical techniques, allowing the detection of many compounds at the nano – pico gram (10^{-9} – 10^{-12} grams/liter) level are common and method development and refinement is near-continual. By contrast, advances in our understanding regarding ecological and human impacts from observed levels of CEC have been relatively slow. We attempt herein, therefore, to identify the subset of issues most relevant to our geological and environmental setting using data from available studies. The reader is advised that information on CEC is rapidly developing and thus today's priorities may give way to findings of emerging research.

Over 350 published papers were reviewed in the compilation of this report. The authors have chosen only to present elements of the published studies that they consider most relevant to Barnstable County on Cape Cod and similar areas where wastewater disposal occurs completely within the aquifer that supplies drinking water and oftentimes has immediate hydraulic connection with both freshwater and marine aquatic habitats.

Literature Review

The range of compounds potentially present in any domestic wastewater is substantial and includes, as mentioned above, pharmaceuticals, personal care products, personal use products (fragrances, shampoos), pesticides, by-products of various manufacturing processes that spread upon use (flame retardants, plasticizers) and others. Pharmaceuticals are inherently designed to be bioactive and have been the subject of recent and comprehensive reviews (Guo et al. 2010; Fatta-Kassinos, Meric, and Nikolaou 2011; Barnes et al. 2008; Crane, Watts, and Boucard 2006). Certain non-ionic surfactants (alkylphenol ethoxalates) also have been the subject of intense study due to their abundance in wastewater and their potential for disrupting the signaling cascade in endocrine systems (Zoller 2006).

While there are numerous studies regarding treatment of CEC in large municipal treatment plants (Joss et al. 2005; Khanal et al. 2006; Lee et al. 2004; Moll et al. 2001; Munir, Wong, and Xagoraraki 2011; Nelson et al. 2011; Petrovic et al. 2002; Polar 2007; Rosal et al. 2010; Sui et al. 2010), there are relatively few studies documenting the treatment of CEC by septic systems. The basis of our understanding of treatment for CEC in septic systems generally comes from actual measurements taken from septic systems and soil column-type studies conducted in laboratories. Studies using data from actual septic systems vary in their level of detail such that no one study was found to comprehensively address the topic of CEC treatment. Most of the studies reviewed below could be classified as a reconnaissance-type; their purpose was to obtain more generalized information on the occurrence of selected CEC in groundwater beneath septic systems as opposed to determining the actual efficiencies of removal for CEC.

While the treatment by septic systems for nutrients and bacterial indicators has received much attention, concomitant studies of CEC treatment is impeded by the following factors. Foremost, standardized methods of assay for CEC are only recently available and, despite some generally-accepted assay methodology, costs often constrain large-scale replicated studies. More importantly, the generally-episodic and highly variable nature of the inputs make standard removal efficiency field studies nearly impossible. In brief, these authors are not aware of any studies involving septic systems where the CEC inputs are sufficiently stable and an adequate number of effluent samples have been collected to allow calculation of removal rates which are commonly performed for nutrient, pathogens and certain other contaminants.

Finally, it is important that the reader be aware of certain features prior to reviewing the studies included in this document. First, the reader is encouraged to avoid making inferences regarding the inclusion of certain contaminants for discussion versus the absence of others; studies below varied in their methodologies and selection of analytes tested. Second, many detection methods and limits have been modified and/or improved since the earliest reconnaissance studies were conducted on the occurrence of pharmaceuticals, hormones and other organic contaminants in the environment (Kolpin et al. 2002). This dictates that direct comparisons of studies across the years 2002–2012 should be approached with caution. Accordingly, the studies included here, while providing valuable information on some apparent trends, do not allow statements regarding the removal of CEC in septic systems except in general terms. Finally, these authors only present below what they consider the most important findings of the studies reviewed. The reader is encouraged to consult the bibliography and review the entire paper for additional details.

Case #1 - Colorado Study

One of the more comprehensive studies to examine a host of endocrine disrupting synthetic compounds was performed using 30 onsite septic systems in Summit and Jefferson Counties in Colorado (Conn et al. 2006). Included among the 30 systems were seven systems equipped with a trickling filter (also referred to as a "biofilter") which achieved significant biochemical oxygen demand (BOD) reductions in wastewater before discharging it to the soil absorption system. The authors found that septic-tank systems equipped with trickling filter components had lower mean concentrations for 10 of the 12 CEC examined compared with standard septic tank-leachfield systems.

A particularly valuable component of this study was data relating to nonylphenol polyethoxylate (NP*n*EO), a surfactant of the alkylphenol class which is common in wastewater. Metabolites of NP*n*EO, notably 4-nonlyphenol, and the nonylphenolethoxycarboxylates (NP1EC, NP2EC, NP3EC, NP4EC), are known to be estrogen disrupting compounds. In three systems equipped with the biofilter, the resulting improvement of BOD reduction in wastewater was concurrent with the breakdown of NP*n*EO and its metabolites. These findings suggesting that additional aerobic treatment of septic tank effluent enhances digestion of 4-nonlyphenol concur with other studies investigating various pharmaceuticals (Matamoros et al. 2009; Topp and Starratt 2000), and suggests that 4-nonlyphenol might be completely metabolized by the biological community if provided enough oxygen. Despite reductions of 4-nonylphenol noted in the Colorado Study however, the post septic tank aeration processes used still resulted in 4-

nonlyphenol concentrations of 130 µg/L following treatment. These levels would exceed the U.S. Environmental Protection Agency-established toxicity-based water quality criteria of 6.6 µg/L.

Case # 2 - La Pine Oregon Study

In a similarly comprehensive study in La Pine, Oregon (Hinkle et al. 2005), an observation network of 28 traditional and advanced onsite wastewater treatment systems and associated downgradient drainfield monitoring wells were used to gain information on the treatment of 63 organic wastewater contaminants ("OWC" by the authors' definition). These OWC included compounds typically found in personal care and household products as well as domestic and industrial wastewater such as caffeine, cholesterol, menthol, camphor, cotinine, detergent metabolites, anti-microbial agents, disinfectants, antioxidants, and compounds originating from deodorants and fragrances. Downgradient monitoring wells located only 19 ft laterally from the suspected source showed substantial reductions in concentrations of OWC higher than that of the conservative chloride tracer used in the study.

Selected data from Hinkle et. al (2005) have been reorganized in Table 1 to show the attenuation of 14 of the 45 OWC observed in the La Pine study. All shaded cells represent system locations where down-gradient wells exhibited no detectable level of the compound indicated. The values in the shaded areas represent the concentration of the contaminant following treatment but before discharge to the leachfield. These data collectively indicate that the soil absorption system of onsite septic systems may be responsible for considerable added treatment following both standard septic tank-soil absorption systems and advanced treatment-soil absorption systems.

Type of System	**3-beta-coprostanol**	**3-Methyl-1H-indole (fragrence)**	**Caffeine**	**Camphor (odor in ointments)**	**Cholesterol**	**D-Limonene (anti-microbial, anti-viral;a fragrance in**	**Indole coffee fragrance, inert ingredient in pesticides)**	**Menthol**	**Methyl salicylate (used in liniments, food, beverages, and U-V absorbing lotions)**	**DEET**	**Phenol**	**p-Cresol**
Standard	11	82	140	3	33	2.8	220	24	0.9	14	630	820
Standard	2	7	2.2	NS	3	NS	NS	8.2	NS	NS	NS	3
Pressure	16	120	5.1	0.9	33	14	38	30	1.2	1.7	160	520
Pressure	38	57	90	0.5	110	0.8	38	NS	1.5	NS	88	340
Sand Filter	33	82	99	1.1	52	1.9	72	72	1.3	0.9	180	640
Sand Filter	12	28	8.8	1	24	0.8	7.6	16	NS	0.8	98	640
Textile Filter	NS	11	3.8	3.4	2	2	0.9	29	NS	NS	32	73
Rotating Biological Contactor	6	NS	9.2	NS	20	NS	4.1	5.9	NS	NS	42	93
Rotating Biological Contactor	15	4	1	NS	20	1.1	17	5.3	NS	NS	44	89
Enviroserver	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	2
Enviroserver	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
FAST	53	24	34	NS	46	0.8	12	25	2	2.9	78	370
FAST	44	19	17	NS	48	1.2	19	24	NS	0.6	53	200
NAYADIC	11	52	18	0.8	32	8.9	34	62	NS	0.6	240	730
NAYADIC	10	17	9	0.9	15	2.7	14	4.3	0.7	52	74	200
Nitrex	7	28	4.7	4.1	16	NS	13	8.8	NS	3.6	56	310
Nitrex	11	66	12	0.6	36	NS	23	21	5.6	0.6	140	540
Puraflo	14	44	21	1.9	28	1.1	24	13	NS	1.4	84	310
Wert B	28	NS	320	19	46	2.9	90	160	6.7	1.1	550	1300
Wert B	12	NS	68	1.9	16	NS	11	24	1.1	NS	94	330

Table 1. Data from Hinckle et. al. (2005) organized to show systems where samples taken from a down gradient well indicated that the analyte was not observed at or above the method detection limit. The value in the shaded area shows the concentration of analyte (µg/L) following indicated treatment but before discharge to the soil absorption system.

Case #3 - Montana Study

A small-scale study in Montana (Godfrey, Woessner, and Benotti 2007) found that ten of twelve compounds (acetaminophen, caffeine, codeine, cotinine, erythromycin, nicotine, paraxanthine, ranitidine, trimethoprim, and warfarin) were removed from a high school's septic tank effluent following its passage through two meters of the sandy vadose zone. Only two compounds, carbamazepine (anti-seizure drug) and sulfamethoxazole (antibiotic) were observed at measurable concentrations in the groundwater, with reductions ranging from 1.8 to 5 times and 15 to 1200 times, respectively. It should be noted that carbamazepine and sulfamethoxazole are two of the most common pharmaceuticals found in wastewater following onsite septic treatment (Clara et al. 2005; Seiler et al. 1999; Kahle et al. 2009; Standley et al. 2008). These results and others cited contrast column studies using six different soil types (Oppel et al. 2004) that suggest that carbamazapine is non-mobile in soils.

Case #4 - North Carolina Study

In this study, five septic systems, each receiving wastewater from at least 25 individuals, were used to evaluate the efficacy of onsite treatment technologies to remove estrogens, nonylphenols and estrogenic activity (Stanford and Weinberg 2010). In four of the systems tested, the presence of an aerobic sand filter reduced the concentration of all estrogenic analytes as well as estrogenic activity as indicated by Yeast Estrogen Screen (YES) assay. Authors of this study contend that, "given the evidence generated in this study pertaining to the efficacy of pretreatment for removing estrogen-active-compounds, an argument could be made for the need for advanced pretreatment option that include aerobic filtration units for the removal of steroid estrogens, nonylphenols and estrogenic activity to protect groundwater quality and surface runoff". While the authors did not examine resulting treatment in the soil absorption system, of particular value in this study was the use of an estrogen-inducible expression system (Routledge and Sumpter 1996) in yeast to indicate estrogen activity of the wastewater. The results of that test were then correlated with actual measurement of the analytes. This technique shows promise for prioritizing wastewater components that generate estrogen-influencing characteristics.

Case #5 - Wisconsin Study

Septic systems from 15 residences in Wisconsin were sampled for 13 target organic wastewater contaminants (OWC). The systems included six suspended-growth aerobic treatment units, seven single-pass sand filters and two systems without any secondary treatment (Wilcox et al. 2009). Concentrations of caffeine, paraxanthine, acetaminophen, and estrogenically active compounds were significantly lower in systems after sand filtration or aerobic treatment compared with effluent from a standard septic tank. This study confirms the role of oxygen during the treatment process in attenuating selected CEC in wastewater. The authors conclude that further studies are necessary to investigate the ultimate fate of OWCs beneath and downgradient from septic systems.

Case #6 - Cape Cod, Massachusetts Study

An extensive array of monitoring points adjacent to a single septic system on Cape Cod was used to characterize the removal/transformation of various organic wastewater contaminants including estrogen and nonylphenol ethoxylates (Swartz et al. 2006). The study indicated that many contaminants exhibited greater reductions concomitant with higher oxygen levels in the entraining groundwater. The mechanisms accounting for these reductions were not clear; however, biological transformation was among the possible explanations. The study describes the septic system as a 2000-gallon septic tank with leaching pits situated approximately 16 inches from the water table. The soils were presumably sandy. Of particular note in this study is the fact that the vertical separation between the bottom of the soil absorption system and the groundwater placed the discharge point of the soil absorption system within the capillary fringe zone of the water table. Some studies (Vepraskas et al. 2007; Abit et al. 2008) suggest that contaminants move horizontally in the capillary fringe area at rates differing from groundwater flow, and therefore, some conclusions of this report relative to removal/attenuation should be examined in light of their possible presence and lack of measurement in the capillary zone.

Case #7 - Massachusetts Alternative Septic System Test Center: Preliminary Study

In cooperation with the U.S. Geological Survey, a reconnaissance-type survey for selected pharmaceutical treatment by various standard and alternative onsite septic system technologies was performed at the Massachusetts Alternative Septic System Test Center (Zimmerman 2005). A comparison was conducted between three aerobic filters (recirculating sand filter, closed-cell foam and sphagnum peat), one aerobic treatment unit (air supplied to septic tank effluent), one upflow anoxic filter (elemental sulfur) and two standard septic tank leachfields (one with five feet and one with two feet of unsaturated sand prior to containment). Due to matrix issues, the common influent wastewater was not assayed, so comparisons are based on the effluent from these common-source systems. The standard septic tank-leachfield system with five feet of unsaturated material beneath the soil absorption system had the lowest number of remaining compounds in the percolate (three) contrasted with the anoxic filter (ten). A surprising observation in this study was the observation of nine remaining compounds in effluent from a recirculating sand filter. The aerobic treatment of wastewater in this particular technology was expected to break down more of the pharmaceuticals present based on work by Stanford and Weinberg (2010). As noted in previous studies carbamazapine and sulfamethoxazole were two of the most persistent pharmaceuticals of those observed.

Case #8 - Cape Cod Ponds Study

The majority of lakes and ponds on Cape Cod are referred to as “kettle” ponds, which are formed from geological processes that have created a direct hydraulic connection with the regional groundwater table. Wastewater disposal sites located in upgradient locations of groundwater flow disperse constituents to the “supply” water of these ponds. Standley et al. 2008 measured the levels of a number of pharmaceuticals in ponds with varying numbers of upgradient homes served by onsite septic systems and found a positive correlation between concentrations of selected pharmaceutical and estrogen-active compounds. Although some authors (Wu et al. 2009) have suspected septic systems as a source for pharmaceuticals and various CEC in surface waters, we believe that the Standley et. al. study is the most compelling evidence published.

Missing from this Cape Cod study are details regarding the types of septic systems incorporated in the research. Septic systems in the area can range from those designed in previous iterations of the Massachusetts Environmental Code, to those designed to the most recent standards (including some advanced treatment units). The relevant variations between systems could include hydraulic loading rates, vertical separation to groundwater, horizontal setbacks to the receiving ponds, and other features that may relate to overall treatment possibilities.

Prioritizing Concerns

The detection of such a wide array of organic compounds in wastewater emanating from septic systems presents a daunting dilemma. Where do we begin in our efforts to address the treatment needs of onsite septic systems? What are the priority contaminants of concern and to what levels do we need to reduce them? These and other similar questions can be summed up in the general question "where do we begin?"

Based on available toxicological data and information from numerous ecotoxicological studies, we suggest that attention first be directed toward three top ranking concerns: endocrine disruption, antibiotic/antimicrobial actions and direct human toxic effects. This ranking is subjective and subject to change as new information develops, however, it represents a starting point from which to begin the process of identifying research needs and best management practices for addressing the issue of CEC in onsite wastewater treatment.

Endocrine Disruption

Numerous studies cited herein indicate the influence of many CEC on humans and wildlife at extremely minute levels. Similarly, studies of groundwater adjacent to onsite septic systems have found many compounds such as hormones and xenoestrogens (i.e., alkylphenols, which are widely produced and used as surfactant) that exhibit endocrine-disrupting qualities in humans and wildlife at the nanogram/L level and below, leading us to consider this issue the most important of the three priorities identified.

As early as the 1990s, researchers identified endocrine disrupting-characteristics in certain wastewater constituents that were shown to exhibit an impact on wildlife species (Routledge and Sumpter 1996; Panter, Thompson, and Sumpter 1998; Colborn, vom Saal, and Soto 1993; Jobling and Sumpter 1993). Subsequent to these studies and following the 2002 national reconnaissance of pharmaceuticals, hormones and other organic contaminants in U.S streams (Kolpin et al. 2002), research and medical communities including the Endocrine Society (Diamanti-Kandarakis et al. 2009; Colborn, vom Saal, and Soto 1993) echoed a concern outlined in numerous review articles and testimonies (SOLOMON 2010) that trace levels of endocrine disrupting compounds were having profound influence on wildlife populations and human health at numerous locations.

While the issue of endocrine disrupting compounds in septic system discharges is substantial, research to date does provide a potential degree of resolution. For instance, some studies suggest that certain xenoestrogenic compounds can be completely mineralized in both aerobic and anaerobic conditions (Ying et al. 2008). Collectively, the data suggest that modifying onsite septic system elements to extend residence time of treatment in the soil system while concurrently providing maximum oxygen supply can optimize the removal of certain CECs, particularly the estrogen and alkylphenol compounds. These strategies will be discussed later in this report.

Antibiotic/antimicrobial Actions

In the environment, antibiotic pharmaceuticals and antimicrobial products have two major effects: (1) they are ecotoxic, which means they directly impair beneficial wastewater microbes, and (2) they impart microbial resistance to potential human pathogens.

Ecotoxic effects

The ecotoxic effects of antibiotics and antimicrobials in the onsite septic system setting is not well studied. However, a study on the effect of the antibiotic tetracycline on nitrogen removal in a soil mesocosm simulating a soil absorption system was conducted (Patenaude et al. 2008) and suggests that toxic effects on denitrifying bacteria were transient and diminished when dosing of the antibiotic ceased. Plants were shown to exhibit toxic effects in the presence of antibiotics commonly prescribed (sulfamethoxazole, sulfamethazine and trimethoprim) (Liu et al. 2009), and these also had effects on soil microbial respiration rates (Liu et al. 2009; Thiele-Bruhn and Beck 2005). The effect of antimicrobials triclosan (TCS) and triclocarban (TCC) on biodegradation of 17β-Estradiol and 17α-Ethynylestradiol in a sandy soil was investigated and found to have no effect at levels up to 100 mg/kg of soil (Shareef, Egerer, and Kookana 2009), however, the authors do provide concentrations at which an ecotoxic effect occurred.

Information on the toxic effect of antibiotics on soil microbiology comes foremost from studies reviewed regarding antibiotics used in veterinary medicine (Sarmah, Meyer, and Boxall 2006; Thiele-Bruhn and Beck 2005) and reveals that significant alteration of soil microbial populations can result when manure from treated animals is applied to soil. The reader should note, however, that antibiotics in veterinary practice are often used on a more continued basis in treatment (for instance to promote growth and feed efficiency in addition to disease) compared with the more episodic nature of their use in humans to combat disease. Accordingly, application of studies involving veterinary use of antibiotics to the onsite setting must be done with caution. Nevertheless it is reasonable to assume that even if episodically applied, antibiotics likely exhibit toxicity to the microbial community used to degrade wastes in onsite septic systems, and this at times will reduce the treatment performance for various contaminants.

Induced antibiotic resistance

The release of antibiotics and certain antimicrobial products to the general environment by any method poses a threat that bacteria exposed at sub-lethal concentrations will develop a resistance to the effect of the antibiotic. Further, once resistance is developed, it can be passed to other organisms, including human pathogens, by conjugation, transduction or transformation. Conjugation is the process by which DNA (the "instruction set" for achieving antibiotic resistance) is transferred by an actual connecting bridge between the two bacteria. Transduction is the process by which the DNA is transferred via a bacteria virus. Transformation can occur when a bacteria receives the DNA by absorbing a plasmid (a small section of DNA with the "instruction set" for achieving antibiotic resistance) from another cell that has been destroyed but has left this DNA-containing element in the environment at large.

Again, the vast majority of literature regarding the proliferation of antibiotic resistance comes from studies of veterinary antibiotics (Sarmah, Meyer, and Boxall 2006; Ghosh and LaPara 2007), however, antibiotic-resistance has also been linked to human sanitary waste disposal practices (Gallert, Fund, and Winter 2005; Kim and Aga 2007; Barnes et al. 2008).

Studies collectively suggest inducement of antibiotic resistance by antimicrobial products and antibiotics in septic systems should remain a primary concern. While in most cases the relatively limited bacteria mobility in a septic system leachfield limits bacterial interactions necessary to proliferate antibiotic resistance beyond an immediate area, study of bacteria plasmids (DNA molecules that can replicate autonomously in the host cell) suggests even bacteria that have been lysed can pass their genetic material through porous soil, extending their effective range for imparting antibiotic resistance beyond the mobility/entrainment range of the parent bacteria (Rysz, Alvarez, and Kroiss 2006). The information carried on the plasmid can provide antibiotic resistance to a microbe capable of absorbing it. Their small size, relative to a host, allows their entrainment in percolating wastewater to a greater extent than a host cell, and likely is equal to that of viruses.

Direct Human Toxicity

Although there are few definitive studies, the direct toxicity of pharmaceuticals at environmentally relevant concentrations to humans is considered by these authors as a priority topic. While there was no evidence of an association between breast cancer and CEC in drinking water in an area dominated by septic systems (Brody et al. 2006), the evidence for human endocrine disruption in many wastewater constituents in various settings has been well documented (SOLOMON 2010). In addition to endocrine disrupting compounds, cancer therapy drugs, which are designed to be cytostatic, have also been found in wastewater (Heberer 2002). While some research efforts have attempted to predict and assess the threat of exposure of these compounds from municipal wastewater systems (Johnson 2008), we have found no research regarding their treatment in onsite septic systems. Again, given the sometimes-proximate distance of a drinking water source to onsite septic systems, this topic should remain a priority research issue.

What Do the Studies Suggest Relative to CEC and Onsite Septic Systems?

The most dominant theme of studies relating to CEC treatment by onsite septic systems is that aerobic conditions facilitate CEC removal (Wilcox et al. 2009; Swartz et al. 2006; Stanford and Weinberg 2010; Conn et al. 2006). Most of the supporting studies demonstrate this effect using pretreatment devices (devices that are positioned between the anaerobic septic tank and the soil absorption system) that expose septic tank effluent to atmospheric oxygen by various means (i.e. trickling or packed bed filters, activated sludge etc). Studies which further investigated subsequent removal in the soil absorption system following this pretreatment showed even further removal of CEC in receiving soils (Hinkle et al. 2005). There appears little doubt that enhancement of aerobic conditions in the onsite septic system treatment train can substantially reduce the concentrations of at least one major class of CEC: the endocrine disrupting compounds of hormones and phenolic surfactants. Thus, there is evidence for hope that both natural and synthetic hormones and alkyl phenolic metabolites (nonylphenol polyethoxylates, 4-nonlyphenol, and the nonylphenolethoxycarboxylates), can be metabolized by microbiological communities present in onsite wastewater systems and converted to innocuous byproducts.

Design Modifications Suggested by Research That Can Mitigate CEC Release to the Environment

Consistent findings that aerobic conditions are more conducive to CEC removal suggest that enhancements to standard septic systems that optimize aerobic digestion would return significant benefit. Accordingly, we provide below a description of the wastewater treatment process in the soil absorption system (SAS)—the aerobic component of a standard septic system—for the purpose of identifying design opportunities which might optimize conditions for the transformation of CEC.

Generally, the aerobic status of the SAS is controlled by a number of factors including the amount and strength of organic wastes applied, the rate of wastewater application, the mode of oxygen delivery (active or passive), the mode of effluent delivery to the soil interface (gravity or pressure), the porosity of the soil, the vertical height of the unsaturated zone and others. In an ideal SAS, wastewater is dispersed in such a manner as to maximize its passage across as many soil surfaces as possible. Further, air is available at a rate necessary to remove the wastewater's oxygen-demanding characteristics and solubilize its constituents. As the wastewater percolates past the immediate soil interface, where very active heterotrophic bacteria action occurs, it enters into a zone more dominated by chemolithotrophs such as nitrifying bacteria. In this unsaturated zone, final chemical transformations occur which result in many organic chemicals further degrading to carbon dioxide and water. It is theorized that in this unsaturated zone the abundant carbon-bearing organic constituents are reduced in abundance such that more trace compounds (such as many CEC) are subject to microbial utilization.

In accordance with the above process description and earlier discussions of conditions conducive to CEC reduction, the following describes system features that should be considered when designing septic systems for optimizing CEC removal.

Pressure Distribution of Effluent

Low pressure distribution of septic tank effluent within the SAS exposes effluent to more soil particles over which thin-film fluid flow will occur and promote oxygen transfer. In the more-commonly used gravity distribution system, the majority of SAS soil interface area is not used and effluent percolates for a period of time under saturated flow conditions through a lower volume of soil. This condition of saturated flow does not allow for the efficient transfer of oxygen to waste-digesting microbes. Accordingly, we recommend low-pressure distribution as a means of optimizing oxygen transfer to wastewater and maintaining unsaturated flow conditions during system operation.

Venting and Shallow Profile Placement

Most onsite wastewater regulations recognize that SAS venting provides enhanced air exchange and promotes wastewater treatment. Again, venting the soil interface area allows transfer of oxygen to aerobic organisms that digest waste. Accordingly, we recommend that all SAS have at least one vent and be placed with minimum cover as allowed by regulations to support maximum air exchange across the SAS. The efficacy of increasing the number of vents or creating configurations that maximize the air supply to standard systems should be subject of further research.

Maximize Vertical Separation

Vertical separation between the bottom of the SAS and a limiting condition, such as groundwater, affords percolating effluent residence time in the microbiological setting that aerobically degrades wastewater constituents. Accordingly, we recommend maximizing this separation where possible as a strategy to increase residence time. As mentioned above, the incremental advantage to increasing vertical separation is not well studied and should be the subject of further research.

Decrease Hydraulic Loading

Hydraulic loading is the volume of effluent supplied per unit area per period of time to the SAS. It is generally expressed as gallons/square foot/day (volume/unit area/time). The hydraulic loading rate is a theoretical value that is often obtained simply by taking a daily flow volume and dividing it by the entire area of *available* SAS soil interface. A reduction in this loading rate theoretically increases residence time in the soil environment before reaching groundwater (as does maximizing the vertical separation as referenced above). Studies suggest that hydraulic loading rates below the presently-allowed loading rates for sand, for instance, should be explored. Loading rates of 2.9 cm/day (approximating the 0.74 gal/sq. ft/day prescribed in Massachusetts) have been shown to significantly reduce alkylphenols (Conn et al. 2006); however, research is still necessary to determine the benefit of incrementally decreasing this loading rate to further enhance treatment.

Summary and Conclusions

The issue of CEC release to the environment through various wastewater disposal practices is complex. Our analytical ability to detect the presence of CEC in the environment at the nanogram per liter level and below is disproportionate to our understanding of the significance of these exposures, particularly to humans. The vast range of compound types and their well-documented modes of action on wildlife physiology also prompts questions regarding the effects of certain CEC to humans enduring long-term exposure; for example, could endocrine disruption in fish from CEC imply a similar effect in humans? After all, it is well known that biochemical processes inherent in many wildlife species are preserved in higher life forms and thus CEC that affect certain biochemical processes may affect these same processes in species phylogenetically removed.

Regarding pharmaceutical antibiotics, sub-therapeutic doses that are passed unchanged through animals and humans undoubtedly impart antibiotic resistance in the very pathogens we seek to treat, however, the implications of this process in the relatively-closed environment beneath a septic system are not understood. Finally, cytostatic and cytotoxic drugs used to treat cancer as well as other directly toxic CEC may not readily be rendered innocuous during the wastewater treatment process and may eventually reenter the consumption segment of the recycle process. Although there are few studies of onsite septic systems to help quantify the environmental/health risk, we intuitively include this topic in our list of priority concerns based on the modes of actions of these toxins.

We have reviewed herein the available studies pertinent to onsite wastewater treatment and disposal. We have identified a common theme; that well aerated systems with long retention times and presumably diverse biological treatment zones affect the highest probability of rendering a wide array of CEC innocuous. This conclusion gives way to recommendations that intuitively promote these conditions in the onsite septic system. We suggest further research to confirm these principles that have been indicated by the published studies cited herein.

Addendum: A Brief Review of Research Conducted by Barnstable County Department of Health and Environment with Comments on Future Direction.

This review of published research articles has led the Barnstable County Department of Health and Environment (BCDHE) to pursue additional information regarding optimization of CEC removal in the onsite septic system setting. In 2010, through its oversight of the Massachusetts Alternative Septic System Test Center (MASSTC), a drip dispersal system following a standard septic tank was installed and tested. Three dispersal sections were installed in the standard manner, while three test cells were supplied additional air using a proprietary technology called SoilAir™. Initial results were promising for at least two of the antibiotic compounds examined (ciproflaxin and sulfamethoxazole), indicating higher removals compared with test cells not supplied the additional air. In 2011, BCDHE installed and is in the process of testing shallow drainfield applications supplied with additional air in order to confirm the role of air in enhancing treatment for CEC in soils-based systems. Finally, in 2012, BCDHE is planning research efforts that will clarify the role of different soil types in the removal of CEC.

Previous research efforts will be supported in 2012 by the acquisition and use of instruments employing high-pressure liquid chromatography with two quadruple mass spectrometers in series. The analytical focus will be prioritized toward hormone compounds and phenolic surfactants. These compounds are considered as having the broadest and most pervasive implication to humans and the environment. It is important to note that although there may be a wider range of CEC potentially present in the environment with various effects, available resources constrain the scope of our investigation.

In addition to the above-described efforts, BCDHE will be investigating all possible ways to corroborate with regional university facilities and others to develop a multi-faceted strategy for systematically exploring sources and implications of CEC in our unique geological setting.

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