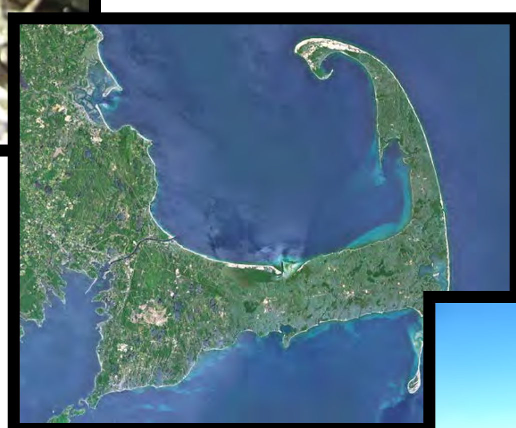
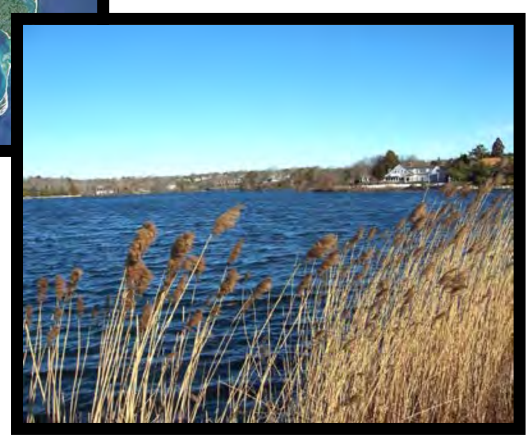
Contaminants of Emerging Concern and Septic Systems:

A Synthesis of Scientific Literature and Application to Groundwater Quality on Cape Cod





Laurel Schaider, Ph.D.
Kathryn Rodgers, M.P.H.
Ruthann Rudel, M.S.

Silent Spring Institute
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EXECUTIVE SUMMARY

OVERVIEW

Hormones, drugs, and household chemicals from wastewater treatment plants are increasingly recognized as threats to water quality and human health. These contaminants of emerging concern (CECs) are now commonly reported in U.S. rivers, streams, and drinking water supplies, and U.S. EPA is asking utilities to monitor for some CECs in drinking water, although regulations establishing allowable levels have not been set. In many regions, discharges from centralized wastewater treatment plants are a major source of CECs into the environment, and CEC removal in these plants has been extensively studied. By contrast, septic systems are likely the primary source of CECs into the groundwater aquifer on Cape Cod, where 85% of residents rely on septic systems. Previous studies by Silent Spring Institute have found CECs in public and private drinking water wells, groundwater, and freshwater ponds. However, there has been limited study of CEC removal in septic systems.

The goals of our study were to synthesize existing information on removal and discharge of CECs from conventional septic systems and centralized wastewater treatment plants and to estimate inputs of CECs into Cape Cod groundwater. We compiled concentration data for 34 CECs from 16 published studies. Among these, we selected nine of the most frequently-tested CECs for quantitative analysis, including pharmaceuticals, personal care product ingredients, and a detergent metabolite that is also a hormone disruptor.

FINDINGS

CEC concentrations reported in septic tank effluent ranged from tens of nanograms per liter (ng/L) to tens of micrograms per liter (µg/L). Some CECs were well-removed in septic system leach fields, with over 99% removal for acetaminophen and caffeine. Other CECs were poorly or moderately removed, with <50% removal of two pharmaceuticals (carbamazepine and sulfamethoxazole) and a flame retardant (TCEP), all three of which we previously detected in Cape Cod drinking water. We estimated that CEC concentrations in discharges from leach fields were generally on the order of tens to hundreds of ng/L and were similar to those found in effluent from conventional secondary wastewater treatment plants.

We used these estimates of CEC concentrations in septic system leachate to estimate loading of nine CECs into Cape Cod groundwater. We modeled loading into Barnstable County groundwater as a whole and into several smaller zones, including areas that recharge drinking water wells and watersheds for coastal ecosystems and ponds. Our results show that while considerable reductions in CEC concentrations occur during onsite treatment, substantial quantities of some CECs are released into Cape groundwater, particularly in densely developed residential areas. Furthermore, failing septic systems and systems with older designs will provide less effective CEC removal.

IMPLICATIONS

Our study suggests that wastewater management planning on Cape Cod should extend its focus on high density residential areas near nitrogen-sensitive coastal ecosystems to also include high density residential areas in recharge areas for drinking water wells. This is important because traditional approaches to reduce nitrogen loading, such as installing wastewater treatment plants, may not reduce CEC inputs. Our loading estimates suggest that effluent from septic systems and centralized wastewater treatment plants contains similar concentrations of CECs. Thus, plans to extend sewer systems may not substantially decrease overall CEC loading, but would change the distribution of these inputs, moving them from newly sewered areas to places where treatment plants discharge.

In addition, the extent of wastewater treatment may alter the concentrations and types of CECs discharged into groundwater. For example, chlorination of wastewater treatment plant effluent prior to discharge may break down or transform some CECs of interest, while also leading to the formation of other chlorinated disinfection by-products that are potentially more harmful. In addition to wastewater treatment plants, other approaches to nutrient reduction are being considered, such as eco-toilets (e.g., composting toilets), enhanced onsite treatment, and decentralized cluster systems. CEC removal associated with alternative wastewater treatment approaches is poorly understood. Upcoming Silent Spring Institute research will evaluate removal of CECs in eco-toilets, a low-cost, sustainable approach for treating wastewater and addressing nutrient pollution.

CONCLUSIONS

Although CECs are not currently regulated in drinking water, significant drinking water contamination is already documented on Cape Cod, and some CECs may be regulated in drinking water in the future. Minimizing wastewater impacts on drinking water will reduce exposures to CECs and may better protect public health. Priorities include:

- Minimizing current drinking water impacts by reducing CEC loading from septic systems and other wastewater treatment into recharge areas for drinking water wells.
- Avoiding new discharges of wastewater treatment plant effluent into areas that recharge public and private drinking water wells.
- Recognizing that wastewater treatment plant discharges will have similar CEC levels as discharges from septic systems, and that disinfection may lead create additional, and potentially harmful, new CECs.

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I. INTRODUCTION

Cape Cod Water Quality and Contaminants of Emerging Concern

Eutrophication of coastal waters throughout southeastern Massachusetts caused by excessive nitrogen is prompting action to improve wastewater management. To comply with the Clean Water Act, Cape Cod towns are developing comprehensive wastewater management plans to meet total maximum daily loads established by the Massachusetts Estuaries Project. On Cape Cod, the major sources of nitrogen inputs into coastal embayments are septic systems, which serve around 85% of Cape residents. Expansion of centralized wastewater treatment plants (WWTPs) is one strategy under consideration to address nutrient loading, especially in densely developed areas. However, many community members and the Cape Cod Commission are also evaluating alternatives that may be less expensive, better maintain local hydrology, and reduce energy and water demands.

At the same time, there are concerns about drinking water quality in the Cape's sole source aquifer. Increasing land development is affecting drinking water quality; the fraction of moderately-impacted public wells (nitrate levels 0.5−5 mg/L) increased from 43% to 55% from 1993 to 2008 (Cape Cod Commission 2009). Although public drinking water supplies still meet standards for regulated contaminants, Cape Cod drinking water is also vulnerable to contamination by unregulated contaminants of emerging concern (CECs), such as hormones, pharmaceuticals, and consumer product chemicals, from septic systems and WWTP discharges. While most CECs are not currently regulated in drinking water, the EPA's Candidate Contaminant List (CCL3) and UCMR3 List (chemicals that public water suppliers must monitor) include some hormones and consumer product chemicals. Silent Spring Institute's studies on Cape Cod have shown endocrine disrupting compounds (EDCs) and other CECs in wastewater, groundwater contaminated by wastewater, ponds, and public and private drinking water wells (Rudel et al. 1998; Swartz et al. 2006; Standley et al. 2008; Schaider et al. 2010, 2011, 2014).

Estrogenic EDCs are of special concern because of potential links to women's health. Scientists have long known that lifetime exposure to natural estrogen is associated with higher breast cancer risk. Over 100 synthetic compounds in industrial and commercial products have been identified as estrogenic, and many have been shown to make breast cancer cells grow in laboratory studies (Rudel et al. 2007). While many of these chemicals are relatively weak estrogen mimics, exposure often involves complex mixtures, and mixtures of synthetic and endogenous estrogens have been shown to have additive effects on reproductive health in animals (Tabata et al. 2001; Brian et al. 2005). These compounds may also affect fertility, reproductive outcomes, and testicular, ovarian, and other hormonally-related cancers (U.S. EPA 1997; Rudel et al. 1998).

The presence of EDCs and other CECs in drinking water is of concern on Cape Cod, where breast cancer incidence is elevated relative to other parts of Massachusetts and the U.S. While historical wastewater impacts on drinking water quality, as evaluated by nitrate, were not associated with increased breast cancer risk in a Cape Cod-wide epidemiological study (Brody et al. 2006), a more recent study suggested wastewater-impacted drinking water was a risk factor for breast cancer in one region of Cape Cod (Gallagher et al. 2010). However, direct measurements of EDCs are necessary to more thoroughly evaluate potential exposures to these compounds through drinking water and understand CEC sources and movement in groundwater.

Recent studies by Silent Spring Institute have measured CECs in Cape Cod drinking water. In 2009, we tested 20 public supply wells in nine water districts for 92 CECs, including pharmaceuticals, hormones, personal care products, perfluorinated compounds, and organophosphate flame retardants (Schaider et al. 2010, 2014). Our results showed that 75% of wells tested contained CECs, indicating that chemicals in household and commercial wastewater can make their way into public drinking water supplies. In general, wells with higher levels of nitrate and boron (both markers of wastewater) and wells in more highly populated areas tended to have more frequent detections and higher levels of CECs. The highest levels of two pharmaceuticals equaled or exceeded the highest levels measured in other studies of U.S. drinking water. The highest concentrations of two perfluorinated chemicals were within a factor of two below health-based guideline values. In 2011, we measured CEC concentrations in Cape Cod private drinking water wells, which serve around 20% of Cape residents (Schaider et al. 2011). We tested for 121 CECs in 20 private wells located in seven towns across Cape Cod, with an emphasis on wells that were likely among the most impacted. Eighty-five percent of wells contained CECs, including an artificial sweetener, an antibiotic, and several perfluorinated chemicals. Overall, it appears that the most impacted wells on Cape Cod are as contaminated as the most contaminated drinking water supplies so far reported in the US.

Our results demonstrate widespread impact of wastewater, primarily from septic systems, on Cape groundwater and drinking water. There are few enforceable drinking water standards for CECs, and health-based guideline values have only been developed for four chemicals we detected; levels in all samples were below guideline values. However, health effects of exposure to low levels of these types of chemicals, especially in complex mixtures, are not yet known.

Wastewater management planning currently underway on Cape Cod is focused on nutrient loading from septic systems and related impacts on coastal and freshwater ecosystems. Our work shows that septic systems also have a significant impact on CECs in drinking water. These compounds are currently unregulated in drinking water, but they are important to address because of potential impacts on the ecosystem and human health. The current priority areas for upgrading or replacing septic systems are focused on impaired coastal waters. Additional wastewater discharges in well recharge areas may increase the impacts of CECs on drinking water quality. Considering CECs in current wastewater management plans would be more efficient, since some of these chemicals may be regulated in the future, and it would also address public health concerns related to the presence of CECs in drinking water. This study addresses important data gaps by synthesizing available information on CEC removal in septic systems and applying the results to estimate loading concentrations of CECs from septic systems and wastewater treatment plants (WWTPs) into Cape Cod groundwater.

Contaminants of emerging concern and septic systems

Decentralized wastewater treatment systems, which can serve individual households, clusters of homes, and businesses, serve about 25% of the U.S. population (U.S. EPA 2005). Their effluents discharge into groundwater, often in communities that rely on groundwater as a source of drinking water (Bremer and Harter 2012). Despite growing awareness of wastewater-related CECs such as pharmaceuticals, hormones, and consumer product chemicals reaching drinking water supplies and aquatic ecosystems, few studies have evaluated CEC removal during onsite wastewater treatment.

Discharges of effluents from WWTPs and septic systems are the primary sources of CECs into surface water and groundwater in many locations. Conventional WWTPs are primarily designed to remove conventional pollutants such as suspended solids, biochemical oxygen demand, pathogens, and in some cases, nutrients, and are not specifically designed to remove CECs. Removal of CECs in WWTPs is variable and depends on many factors, including the type of treatment, solids retention times, levels of organic matter, and characteristics of each chemical. Dozens of journal articles have characterized CEC removal during conventional secondary treatment and advanced treatment steps (reviewed by Oulton et al. 2010; U.S. EPA 2010). In general, activated sludge removes many CECs, although some chemicals are more persistent and require longer solids retention times or advanced treatment processes to achieve removal (Kreuzinger et al. 2004). Other CECs are highly persistent across many types of treatment, including some organophosphate flame retardants (e.g., TCEP), fragrance compounds (e.g., galaxolide), pharmaceuticals (e.g., carbamazepine) and perfluorinated chemicals (e.g., PFOS) (Stephenson and Oppenheimer 2007; Drewes et al. 2009; Guo et al. 2010).

Onsite wastewater treatment systems can be sources of pollutants to drinking water wells and surface water bodies, especially in rural and suburban areas (Verstraeten et al. 2005; Bremer and Harter 2012). Standard septic systems have two main components: a septic tank, which allows for settling of solids and flotation of grease and oils, and a soil absorption system (also called leach field, drainfield, or tile bed), in which septic tank effluent is distributed from pipes or pits into porous vadose zone soils (Figure 1). The soils of the soil absorption systems develop diverse microbial communities and biofilms that can attenuate pathogens and some pollutants. Nitrogen is typically not well removed in conventional septic systems; around 25% removal of total nitrogen was measured in typical soil absorption systems (Costa et al. 2002). Alternative onsite treatment systems include wetlands, membrane bioreactors, sand filters, aerobic treatment units, and biofilters.

Despite the prevalence of septic systems throughout the U.S. and worldwide, less than 20 studies have addressed CEC removal in septic systems. In general, studies of septic systems have shown that little CEC removal occurs in the anaerobic conditions of the septic tank (Wilcox et al. 2009; Stanford and Weinberg 2010) and in anaerobic groundwater within wastewater plumes (Swartz et al. 2006). By comparison, substantial reductions in CEC concentrations can occur within soil absorption systems, through a combination of sorption and aerobic biodegradation processes (Conn and Siegrist 2009; Heufelder 2012a). Advanced onsite treatment (Hinkle et al. 2005; Stanford and Weinberg 2010) and design modifications to leach field design (Heufelder 2012a) can enhance CEC removal, especially steps that include aerobic conditions. To date, little work has been done to synthesize existing studies of conventional septic systems to estimate CEC concentrations in groundwater discharges from septic systems or to apply this information to estimate CEC loading into impaired and vulnerable aquatic systems.

II. Goals and Objectives

Evaluating how wastewater management decisions may affect loading of CECs into groundwater and surface water resources requires an understanding of CEC discharges from onsite and centralized treatment systems. Furthermore, future modeling CEC inputs into aquifers where septic systems are prevalent will require estimated concentrations of CECs discharged from septic systems. While many factors affect CEC removal in septic systems, synthesizing existing studies can provide estimated effluent concentrations that can be used for modeling and planning. These estimates are also useful for comparing the relative effectiveness of conventional onsite and centralized treatment systems. The overall goals for this project were to:

- Facilitate expansion of Cape Cod wastewater planning to include consideration of CECs.
- Provide useful information about CEC discharges from septic systems to other communities in Massachusetts and throughout the U.S. where septic systems are prevalent.

Few studies have evaluated CEC removal in onsite treatment systems, and there has been little work done to synthesize available information. The specific objectives for this project were to:

- Compile existing information about CEC removal and effluent concentrations associated with onsite wastewater treatment systems.
- Compare CEC concentrations in effluent from onsite wastewater treatment systems and centralized wastewater treatment plants.
- Estimate CEC loading into Cape Cod drinking water recharge areas and watersheds for ponds and coastal embayments.

III. Methods

Data collection for CEC removal in septic systems

We compiled published information about CEC concentrations in septic tank and leach field effluent. We used these concentrations to calculate CEC removal efficiencies in leach fields, and applied these removal efficiencies to studies in which CECs were only measured in septic tank effluent. We also collected information about the characteristics of test systems in each study and ancillary water quality parameters. Concentrations of CECs in leach field effluent were compared to those found in effluent from conventional wastewater treatment plants, and median CEC concentrations in these effluents were used to estimate CEC loading into Cape Cod groundwater.

We searched the Web of Science database, including forward searches, for peer-reviewed journal articles containing information about any of our 40 CECs of interest measured in onsite treatment systems. We also included relevant reports and presentations from bibliographies of articles and Google searches. We identified 16 studies of CEC removal in septic systems, including journal articles, reports, and conference proceedings (Table 1). For this study, we compiled information only from standard septic systems, although we also noted any advanced onsite treatment types included in the publications that met our criteria. All of the studies we gathered reported CEC concentrations in septic tank effluent (STE) and/or in groundwater beneath a leach field (also called soil absorption system, SAS). Some studies provided summary statistics across multiple systems, while others presented results for individual systems. When possible, we contacted study authors for additional information about detection limits, nitrogen concentrations, and clarification about sample types. Table 1 shows information about each study. Within each study, we compiled information about the number of people served, type of facility served (e.g., high school, office building, single residence, multiple residences), types of advanced treatment, number of CECs tested for, and number of individual systems tested.

The type of information available varied by study. Most studies reported CEC concentrations in STE, and a subset of these also measured LFE concentrations. Two studies only provided CEC concentrations in LFE (Zimmerman 2005; Zimmerman and Heufelder 2007). Some of the field-scale studies included paired measurements of CECs in septic tank effluent and leach field effluent, which allowed us to calculate a leach field removal efficiency for each chemical using the ratio of these concentrations. We also included the removal efficiencies reported in one laboratory-based study that measured CEC removal in soil columns designed to represent leach field conditions (Teerlink et al. 2012b). For each chemical, the average calculated removal efficiency was applied to studies with only CEC measurements in STE in order to estimate a predicted LFE concentration. Results from one study with high inputs of nonylphenol into its septic tank, based on a simulated pattern of 3 wash loads of laundry each day, were used only to calculate removal efficiencies since the concentrations may be higher than those found in wastewater coming from households with more typical laundry use.

We collected available information about the distribution of measured concentrations and characteristics of treatment systems from each publication. We compiled all available concentration data (individual measurements, means, medians, maxima, minima), as well as detection frequencies, detection limits, recovery information, number of systems tested, and number of people served by each system. We used values from single systems whenever possible. If a single system was sampled multiple times, individual measurements from that system were averaged, and the average value was used to represent that system. If data were only available for multiple systems, we compiled summary statistics for the entire distribution (mean, median), not just for detected values, to avoid biasing our results high. When publications reported measured values as estimated values, we used the estimated measurements, with a corresponding qualifier flag in our database. We collected detection limits when they were available in each publication, and contacted study authors when they were not included. We included values presented in tables or text. In some cases, concentrations were derived from graphs using DataThief, a free online program that extrapolates values from linear and log-scale graphs (Tummers 2006). For nine measurements, we compared DataThief results presented in a graph to numerical concentration data presented in a table or within manuscript text, and we generally found agreement within 7%. We did not include concentration values if graphs were not clear or if values were too close to the axes, or if the resolution appeared too grainy to accurately identify axes and markers.

Septic tank effluent. Most field studies, with the exception of Zimmerman (2005) and Zimmerman and Heufelder (2007), provided CEC concentrations in septic tank effluent. Most studies included systems with just one septic tank, while others presented effluent concentrations from a series of septic tanks. Because the emphasis of our study is on discharges into the environment, and because most CEC removal in septic systems occurs in leach fields, we did not compile septic tank influent concentrations. In addition, influent concentrations and flow rates are extremely variable, especially for individual household systems, and thus much harder to sample in a representative manner. Septic tank influent also poses greater analytical challenges due to matrix effects and the presence of suspended solids. Septic tank effluent studies were excluded if the effluent measurements were from blackwater (wastewater from toilets) systems only, because blackwater is not representative of typical septic tank influent, if septic tank influent and effluent values could not be distinguished, or if effluent from subsequent tanks was recirculated back into septic tanks.

Leach field effluent. Evaluating CEC removal in leach fields and concentrations of CECs in percolate from these systems being loaded into groundwater is difficult, and a majority of the studies we compiled did not collect groundwater samples under the soil absorption system, even though they are an integral part of the systems and where most CEC removal is expected to occur. These samples are more difficult to collect since there is not a single pipe or sampling port. In most cases, samples were collected from lysimeters that sampled vadose zone soils beneath leach fields. Two studies (Zimmerman 2005; Zimmerman and Heufelder 2007) were conducted at the Massachusetts Alternative Septic System Test Center (MASSTC), where the bottoms of soil absorption systems are lined with impermeable liners that allow for measurement of percolate flow rates and collection of percolate samples. From other studies, we selected groundwater samples that would be most similar to percolate samples under a Title 5 system, which typically include two feet of sand through which the wastewater percolates and is filtered. Conn (2010b) collected groundwater samples 60, 120, and 240 cm below infiltration of STE, and we selected the 60 cm depth since that was closest to two feet. Carrara et al. (2008) tracked plumes from three septic systems, and we selected the samples that were most directly under the infiltration lines, although these were much deeper (2-3 m below infiltration of STE). Leach field effluent samples were excluded from our study if they were not measured below leach lines.

Results from single-pass sand filters (non-recirculating) were included from a small number of studies as surrogate measures for leach field effluent. The filtration through unsaturated, porous soil is similar to conditions within leach fields. However, sand filters may vary in their ability to treat wastewater; for instance, wastewater moves more rapidly through pressurized sand filters than a gravity-fed sand filter.

Laboratory studies of soil absorption systems. Teerlink et al. (2012b) conducted soil column experiments to mimic fate and transport of CECs in a leach field. While most studies did not state the hydraulic loading rate (i.e., volume of water dispersed per unit area per unit time), Teerlink et al. tested two HLRs, 2 and 8 cm/day. We selected 2 cm/day, which was closest to the HLR specified in Title 5 regulations for well-draining soils (0.74 gallons/ft^2/day = 3.0 cm/day). Since the Teerlink et al. study used artificial wastewater spiked with known concentrations of CECs, we did not use the concentrations in the column leachate, and only included the removal efficiencies in our compilation.

Selecting CECs of interest

We selected approximately 40 CECs of interest for our compilation of published septic system studies. We included chemicals that we had detected in our studies of public and private drinking water wells, ponds, and groundwater on Cape Cod, as well as chemicals that have been frequently detected in other studies of groundwater and surface waters (e.g., Kolpin et al. 2002; Barnes et al. 2008; Focazio et al. 2008). We found either septic tank and/or leach field concentration information for 35 of these chemicals. Appendix 1 summarizes these 35 chemicals, along with the number of systems for which septic tank or leach field effluent data were available, the maximum concentration detected, and the chemical CAS number and log K_{ow}, as calculated from the KOWWIN v1.68 component of EPI Suite (U.S. EPA 2000b).

Among these chemicals, we selected nine chemicals for further characterization and inclusion in our modeling component. The selected chemicals represented a range of likely removal efficiencies in during wastewater treatment, as assessed by removal during conventional activated sludge treatment in sewage treatment plants (Oulton et al. 2010; U.S. EPA 2010). We only included chemicals for which we could find both measured septic tank and leach field effluent concentrations, and aimed to include chemicals for which we had data from multiple studies with the goal of having the most representative sampling possible. The final nine chemicals are listed in Table 2 and include three prescription medications (carbamazepine, sulfamethoxazole, trimethoprim), two non-prescription medications and pharmaceutically-active compounds (acetaminophen, caffeine), two personal care product ingredients (DEET, triclosan), a detergent metabolite (nonylphenol), and a flame retardant/plasticizer (TCEP). Nonylphenol is an endocrine-disrupting compound that is a weak estrogen mimic and has been linked to endocrine disruption in fish (Tabata et al. 2001). Sulfamethoxazole is an antibiotic that has been shown to alter biogeochemical transformations of nitrogen in Cape Cod groundwater (Underwood et al. 2011) and microbial community structure (Haack et al. 2012).

Data collection for WWTP compilation

In general, CECs have been better characterized in WWTPs than in onsite treatment systems. We started gathering influent and effluent concentrations from two reviews of CEC removal in WWTPs, Oulton et al. (2010) and a US EPA database (2010). Our goal was to identify at least five WWTP studies for each of our nine main CECs of interest. In order to consistently compare biological treatment in WWTPs and in leach fields, we selected only measurements of effluent after primary treatment and secondary treatment with activated sludge. WWTP effluent measurements collected after tertiary treatment and disinfection were excluded, because these treatment processes are not uniformly used on the Cape, and they can further remove and transform CECs. We identified 22 studies of CEC removal after primary treatment and conventional activated sludge treatment in WWTPs, including journal articles referenced in Oulton (2010), a US EPA database (2010), and PubMed database searches. These articles are listed in Appendix 2. We compiled information about influent and effluent CEC concentrations, location, number of treatment plants sampled, and population served. Only municipal WWTPs were included in our data compilation. When the same treatment plant was sampled multiple times, an average of those measurements was calculated to represent that system.

Data analysis

Calculating median and maximum values for effluent from septic tanks and leach fields. For prescription pharmaceuticals, we only used studies based on systems serving multiple residences or non-residential sources that provide a more representative sampling across households and the general population. Prescription medications are unlikely to be present in a small sample of septic systems serving individual households, since at any given time only a small portion of households are likely to use them. Systems serving multiple households or non-residential areas, such as office buildings, may provide an estimated concentration that is more reflective of the concentration entering groundwater from many individual households.

We reported a median and maximum concentration in septic tank effluent for each CEC of interest (Table 4). To calculate median values, measured values were used whenever possible, and one-half of the reporting limit (RL) was substituted when concentrations were non-detectable. When sorting concentrations in order to calculate a median, values below the detection limit were ranked lower than measured values, even when reporting limits were higher than measured values. Detection frequencies for all nine CECs of interest were above 50%, so all median values were based on measured values.

Calculating summary statistics for LFE required several steps. First, removal efficiencies were calculated based on paired STE and LFE measurements from field studies and from one column experiment (Teerlink et al. 2012b). From these, we calculated a median percent removal and applied it to each septic tank effluent value (or ½ DL if a value was not detected), to calculate a predicted LFE value. To calculate a median LFE concentration across all studies, we used reported values for systems with measured LFE concentrations, and we used predicted LFE values for those systems that did not provide a measurement from a leach field. When LFE concentrations were below their respective reporting limit (RL), we compared the predicted LFE value to the RL for the LFE measurement. If the RL for the LFE measurement was above the predicted value, we used the predicted value. If the RL for the LFE measurement was lower than the predicted value, we used one-half of the RL for the LFE measurement. Because there is limited information available about CECs in leach fields, it is important to note that our median values should be regarded as order of magnitude estimates. Maximum STE and LFE concentrations were based on individual measurements from any system. For some chemicals, the maximum LFE concentration was a predicted value based on a measured STE concentration and estimated removal efficiency.

Calculating median and maximum values for WWTP effluent. Unlike the septic system measurements, pharmaceutical measurements were included for all treatment plants, because they serve large populations and may provide a representative estimate of prescription pharmaceutical use. To calculate median and maximum values, all WWTP effluent values were included, and one-half RL was substituted for values that fell below the RL.

Selecting areas of interest

We characterized CEC loading into recharge areas for selected public and private wells and coastal embayments and ponds, as well as for Barnstable County as a whole (Figure 2; Table 3). We included several wells and ponds in which we previously detected CECs that we could use for comparison to our CEC loading estimates. Our results provide a benchmark against which we can compare CEC loadings in other areas and can potentially be used to identify additional areas that may be vulnerable to CEC inputs.

Public wells. In selecting public wells, we chose wells that included a range of likely wastewater impacts, which an emphasis on wells most likely to be impacted by septic systems. We selected eight of the 20 public wells that we tested in 2009 (Schaider et al. 2010, 2014). These eight wells are located in four water districts, all in the Town of Barnstable. Three of these wells contained detectable levels of at least eight CECs, four wells contained three or four CECs, and one well did not contain detectable levels of any CECs.

Private wells. Private wells may be more vulnerable to CEC contamination than public wells since they tend to be located in closer proximity to septic systems and other sources of groundwater contamination. In 2011, we tested for 121 CECs in 20 private wells (Schaider et al. 2011). Of these, 17 contained detectable levels of at least one CEC. For this study, we selected an area of Eastham, one of three towns that rely on private wells for all or nearly all residents, near Campground Beach. This is an area with nearly 100% residential development that likely also serves as a recharge area for some private wells.

Watersheds. While the effects of nutrient loading into the waters of Cape Cod are well-recognized, the systems most impacted by nutrients also may be most vulnerable to effects of CECs. Coastal embayments and kettle ponds that are impacted by wastewater may accumulate CECs in the sediments, water, and biota, and accumulation of EDCs and other CECs in aquatic ecosystems can have ecological health implications. In 2012 and 2013, the Provincetown Center for Coastal Studies tested for four pharmaceuticals (acetaminophen, carbamazepine, sulfamethoxazole, trimethoprim) and a nicotine metabolite (cotinine) at nearshore and offshore locations in Cape Cod Bay and Nantucket Sound (Costa et al. 2013). These chemicals were frequently found in the samples tested, with concentrations of acetaminophen reaching 10 ng/L in Nantucket Sound. These results demonstrate the CECs from groundwater and rivers can be discharged into coastal waters and persist at detectable levels even after dilution and transport into open water.

We selected two coastal embayments that are impacted by nutrient loading from both septic systems and wastewater treatment plants. These receiving waters are of interest because proposed sewering plans could increase wastewater discharges into their watersheds. West Falmouth Harbor is a "moderately to highly nutrient enriched shallow coastal estuarine system" (Howes et al. 2006) that receives nutrients from both septic systems and the Falmouth Wastewater Treatment Plant. Lewis Bay (Barnstable, Yarmouth) is at risk of eutrophication caused by nutrient loading and is impacted by both septic systems and the Barnstable Water Pollution Control Facility (BWPCF) (Howes et al. 2007). The recommended percent reductions in total nitrogen load for West Falmouth Harbor and the Lewis Bay system are 56% and 27%, respectively.

We also selected two ponds that we found to contain pharmaceuticals and hormones in our 2008 study of six Cape Cod ponds (Standley et al. 2008). Lewis Pond is a 4.6-acre freshwater pond in Barnstable that had the highest levels of three hormones in our study and relatively high levels of dissolved organic carbon. Oyster Pond is a 62-acre brackish pond in Falmouth that had the highest levels for three pharmaceuticals in our 2008 study. Both of these ponds have low (1/2–1 acre lots) to medium (1/4–1/2 acre lots) density development, along their perimeters in the upgradient direction.

Estimating wastewater flows

Annual wastewater discharges from septic systems and centralized WWTPs were estimated in two ways. For each of eight public wells in the Town of Barnstable, we estimated wastewater flows in two areas: Zone 2 wellhead protection areas, which include the entire land area that potentially contributes water to each well under extreme conditions (six months drought, maximum pumping rate), and Zones of Contribution (ZOCs), which represent the recharge area under a typical usage scenario.

An online, GIS-based planning tool developed by the Cape Cod Commission, WatershedMVP (Cape Cod Commission 2013), was used to estimate wastewater flows into coastal embayments, ponds, an area served by private wells, and Barnstable County as a whole. Discharges from septic systems and WWTPs into recharge areas for public wells were calculated by Tom Cambareri of the Cape Cod Commission using CommunityViz, a GIS-based decision-support tool.

Barnstable County. For Barnstable County as a whole, we summed annual wastewater discharges from unsewered parcels across all of Barnstable County using WatershedMVP. For WWTPs, we summed the discharges from the five centralized WWTPs and from the two septage treatment facilities. For the Barnstable, Chatham, Falmouth, and Provincetown WWTPs, we applied the flow rate provided in WatershedMVP. For the Massachusetts Military Reservation (MMR) WWTP in Sandwich, we estimated the wastewater flow based on the permitted discharge and on the average ratio of actual to permitted discharge rates for the other four WWTPs. For the two septage facilities, we used typical annual discharge rates for the Tri-Town Septage Treatment Facility in Orleans (Wright-Pierce 2005) and the Yarmouth-Dennis Septage Treatment Facility (CDM 2012).

Watersheds. Wastewater from septic systems was estimated for watershed areas and a portion of the town of Eastham using WatershedMVP. For the Lewis Bay system, West Falmouth Harbor, and Oyster Pond, the watershed delineations were already developed for the MEP project and available within WatershedMVP. For Lewis Pond in Barnstable, an approximate watershed was drawn based on groundwater contours by Tom Cambareri. The two coastal watersheds, Lewis Bay and West Falmouth Harbor, also receive WWTP discharges. For West Falmouth Harbor, we assumed that all of the discharge from the WWTP was discharged into the harbor's watershed. For Lewis Bay, we consulted Walter (2008) to evaluate typical flow paths of effluent infiltration under current conditions. We also assumed that 100% of the discharge from the Barnstable Water Pollution Control Facility ends up in Lewis Bay, based on particle tracking maps from the facility (Walter 2008) and based on the Massachusetts Estuaries Project assessment of wastewater sources into the Bay (Howes et al. 2007).

Public well ZOCs and Zone 2 areas. Wastewater flows from septic systems and WWTPs into public well ZOCs and Zone 2 areas were calculated using CommunityViz, which provided an estimate for each parcel within these zones. Several zones were also impacted by the BWPCF. We estimated that the Hyannisport ZOC received 0.02 mgd (millions of gallons per day), out of a total 1.62 mgd, from the BWPCF, based on a modeling estimate by Walter (2008) of the volume of WWTP effluent that was pumped by the Hyannisport Well. The Zone 2 for the Hyannisport well appeared to intersect a sizable portion of the effluent, based on the flow path model in Walter (2008), so we estimated that one-third of the WWTP effluent ends up in the Hyannisport Zone 2. The Zone 2 for the Maher/BFD2/Airport wells appeared to intersect only the outer edge of the likely flow paths for the treatment plant effluent, so we estimated that this area receives 1% of the WWTP flow.

Calculating total nitrogen and CEC loading into groundwater

For each area of interest, we combined calculated flow rates and CEC concentrations to calculate a loading (in units of mass per time) and a loading per area (in units of mass per time per area) using the following equation:

$$\text{CEC mass loading (g/y)} = C_{SS}*Q_{SS} + C_{WWTP}*Q_{WWTP}$$

where C represents CEC concentration and Q represents flow rates for septic system (SS) and wastewater treatment plant effluents. For C_{SS}, we used the median value of predicted and measured leach field effluent concentrations. Although we did have concentration information for residential and non-residential sources for some of our chemicals, we did not attempt to match flow rates from specific land uses with source-specific concentrations given the limited sample sizes. For C_{WWTP}, we used the median WWTP effluent concentration from our compiled literature values.

CEC concentrations in wastewater on Cape Cod may differ from the typical values that we applied from our compiled literature values. Estimated CEC concentrations from WWTPs may be overestimates because some Cape Cod WWTPs include addition treatment steps that may enhance contaminant removal and/or transformation. For instance, Falmouth's WWTP includes a UV disinfection step prior to discharge, and previous studies have shown that UV disinfection can reduce levels of some contaminants. In addition to WWTPs and individual systems, there are also 13 cluster systems (1,000 to 10,000 gallons per day) and 44 satellite plants (>10,000 gallons per day) (Wright-Pierce et al. 2004). Approximately 650 of the onsite systems through the Cape have advanced treatment. While some of the results in our compilation are applicable to the cluster systems and advanced onsite systems, we have less information about CEC loading from larger, satellite plants, and little information about exactly the alternative treatment approaches used on the Cape. Thus, in our current model, C_{SS} was used to estimate CEC concentrations in wastewater from cluster and satellite systems; actual CEC values from these systems are unknown.

We also calculated total nitrogen loading into each area of interest. For septic systems, we applied a value of 26.25 mg/L, which is the standard concentration used in the Massachusetts Estuaries Project methodology, derived from a study by Costa et al. (2002). For the Barnstable WWTP, we applied a concentration of 5.5 mg/L, and for the other four treatment plants, we used a total nitrogen concentration of 10 mg/L, which are the concentrations used in WatershedMVP. We did not directly use the nitrogen loading values provided by WatershedMVP, since they include attenuation factors that account for losses of nitrogen as wastewater passes through ponds. For the two septage facilities, we used an average total nitrogen concentration of 35 mg/L for the Tri-Town Septage Treatment Facility in Orleans (Wright-Pierce 2005) and the permitted concentration of 10 mg/L for the Yarmouth-Dennis Septage Treatment Facility (CDM 2012). For this study, our goal was to calculate inputs into groundwater within each zone; it is important to note that losses of nitrogen and of CECs are expected during groundwater transport.

IV. RESULTS

CECs in septic tank effluent

CEC concentrations in septic tank effluent concentrations varied by three orders of magnitude, from tens of nanograms per liter (ng/L) up to tens of micrograms per liter (μg/L) (Table 4). The highest median and maximum concentrations were observed for acetaminophen, caffeine, and nonylphenol. The lowest median concentrations were observed for two prescription medications, sulfamethoxazole and carbamazepine, and for TCEP, a flame retardant and plasticizer. The median concentration for trimethoprim was higher than for sulfamethoxazole, even though these two antibiotics are often used together in mixtures in which sulfamethoxazole is present in higher quantities, suggesting that trimethoprim may be more likely to be excreted.

CECs in leach fields

Median concentrations were lower in leach field effluent than in septic tank effluent for eight of nine CECs of interest. Sulfamethoxazole was the only compound with a median concentration that was estimated to be higher in leach field effluent than in septic tank effluent. These results were based on different sets of studies, so these results should not be interpreted as formation of sulfamethoxazole within septic systems. Median concentrations of five CECs (TCEP, nonylphenol, DEET, sulfamethoxazole, and triclosan) were within the same order of magnitude in effluent from septic tanks and leach fields, while median concentrations of two CECs (acetaminophen and caffeine) were more than 100 times higher in septic tank effluent than in leach field effluent. Because of differences in chemical removal among CECs, the chemicals with the highest concentrations in septic tank effluent did not necessarily have the highest concentrations in leach field effluent. The three CECs with the highest concentrations in septic tank effluent were acetaminophen, caffeine, and nonylphenol, and the three CECs with the highest concentrations in leach field effluent were caffeine, nonylphenol, and sulfamethoxazole. Maximum concentrations for other CECs in our compilation (Appendix 1) were generally similar within each chemical use category (e.g., prescription pharmaceuticals). Hormones were generally detected at low levels within septic tank effluent (tens to hundreds of nanograms per liter), and most were not detected in leach field effluent.

We generally found that median CEC concentrations in leach field effluent were similar to those found in following conventional activated sludge in WWTPs. For seven of the nine CECs, median concentrations in leach field and WWTP effluent were within the same order of magnitude. The largest differences in median concentrations were observed for caffeine, which was 10 times higher in WWTP effluent, and for nonylphenol, which was 20 times higher in leach field effluent. Seven of the nine CECs had higher maximum values in leach field effluent than in WWTP effluent, with up to nearly 40-fold higher concentrations for nonylphenol, indicating a higher degree of variability in septic system effluent.

Removal efficiencies

Removal efficiencies within leach fields varied considerably among CECs and across studies. Several CECs showed a high degree of removal within leach fields, including acetaminophen, caffeine, and triclosan, while the lowest median removal efficiencies were observed for sulfamethoxazole, carbamazepine, and TCEP. For each chemical, removal efficiencies often varied widely across studies; for instance, removal efficiencies for TCEP varied from 0 to 80%. Each field study had different design parameters, such as depth of groundwater samples relative to leach lines, hydraulic loading rate, wastewater composition, and soil types within the vadose zone, which may have contributed to the observed variability in removal efficiencies. The experimental soil column study (Teerlink et al. 2012b) generally found lower removal efficiencies than median values derived from field systems. Biogeochemical conditions and microbial community structure can differ greatly between laboratory and field settings in ways that can affect both sorption and degradation processes. It is important to note that apparent removal using current methods may be driven by major and, in some cases, minor transformations to the chemical structure; triclosan appears to be well-removed during septic system treatment, but its degradation products persist in the environment and raise health concerns (European Commission, 2010).

Wastewater and nitrogen inputs into areas of interest

Table 5 shows estimated loadings of wastewater and total nitrogen (TN) into the Cape aquifer as a whole and into this study's selected areas of interest. We normalized these loadings by area (in square miles, mi^2) to account for the size of each zone. We calculated Cape-wide average values of 25 mgy (million gallons per year) of wastewater per mi^2 and 2300 kg (kilograms) of TN per mi^2. Five of the public wells had wastewater flow and TN loadings into their ZOCs and Zone 2 areas above the Cape-wide average, which is generally consistent with the finding that four of these five wells had nitrate concentrations above 1.5 mg/L (2012 data, from Damon Guterman, MassDEP), a clear indication of anthropogenic impact (background levels of nitrate in Cape Cod groundwater are ≤0.2 mg/L; Silent Spring Institute 1997). By contrast, the three other public wells had predicted wastewater and TN loadings less than half of the Cape average; these wells all had nitrate concentrations below 1 mg/L, indicating less anthropogenic impact. Estimated TN loading per mi^2 into a residential area in Eastham was higher than all other areas of interest. Loadings per unit area of wastewater and TN were above the Cape-wide average for the watersheds both Lewis Bay and West Falmouth Harbor, whereas the watersheds serving Lewis and Oyster Ponds were below the Cape-wide average.

Inputs of CECs into areas of interest

Table 6 presents estimated loadings of our nine CECs of interest in the entire Cape aquifer and smaller areas of interest. Nonylphenol had the highest predicted total loading into the Cape aquifer as a whole, with 10 times greater predicted loading compared to all other CECs in our study. Once normalized for land area, all other chemicals had estimated loading values within the same order of magnitude, with the exception of trimethoprim, which had a predicted loading 10 times lower than all other compounds. These trends are consistent with median leach field effluent values from Table 4; nonylphenol was the highest estimated leach field effluent concentration, while trimethoprim had the lowest.

For the eight public wells in our study, we compared our CEC loading estimates to actual CEC concentrations in 2009 as part of our public wells study (Schaider et al. 2010; 2014). In general, wells predicted to have the highest CEC loading per unit area were also the ones with the highest levels of measured CECs. For example, the three public wells with the highest measured sulfamethoxazole concentrations (Arena 3&4, 110 ng/L; Hyannisport, 41 ng/L; Lumbert Mill 9, 37 ng/L) were also the ones that had the highest predicted sulfamethoxazole loading into their respective Zone 2 areas and ZOCs. However, there were some discrepancies between observed concentrations and predicted loading. For example, our public well study showed that in 2009, the Harrison Well did not contain detectable levels of CECs and nitrate, but the predicted CEC and TN loadings were generally close to the Cape-wide average and were consistently higher than several other public wells in which we did detect CECs in 2009. A better understanding of the land use patterns and characteristics of onsite wastewater treatment types within the Harrison well Zone 2 and ZOC areas may explain these findings. Private wells located in densely developed areas served by onsite treatment also are likely to contain CECs. A residential area in Eastham had predicted CEC loadings that were generally higher than those associated with the recharge areas for public wells.

A wide range of CEC loading rates was observed among the watersheds we analyzed. The Lewis Bay system watershed area contributes on average 15% (range: 6-37%) of Cape-wide loading even though it constitutes only roughly 3% of the Cape's land area. This result reflects discharges from some of the most densely developed areas and the largest WWTP on Cape Cod. Per area loadings estimated for Lewis Bay and West Falmouth Harbor were similar to each other and to the public well recharge areas with the highest predicted loading. In poorly-flushed portions of these coastal embayments, elevated levels of some CECs may accumulate. The watersheds for Lewis and Oyster Ponds had lower predicted CEC loading than the Cape-wide average and most of the public well recharge areas. Nevertheless, these were ponds in which hormones and pharmaceuticals were detected in our 2008 study, suggesting that they are impacted by septic systems. Small ponds have relatively small watersheds, so the characteristics of the septic systems within those areas may have a large impact on pond water quality. In some cases, there is little to no buffer zone between the locations of houses and the edge of the pond, suggesting that proper maintenance of septic systems is especially important in these areas.

V. Discussion

This study provides the most complete compilation to date of CEC concentrations discharged from conventional septic systems and removal efficiencies in septic system leach fields. This compilation allows comparisons between discharges from septic systems and from WWTPs, and provides necessary information for future modeling efforts. It should be noted that there are few studies that have measured CEC discharges from septic systems, and thus this study can only provide order of magnitude estimates of concentrations and loading into groundwater.

CEC removal in septic systems

The results of our study show that CEC concentrations in vadose zone and groundwater samples below leach fields are typically in the range of 10-1000 ng/L, with much higher concentrations associated with some individual systems. These concentrations are one to two orders of magnitude lower than the concentrations typically found in septic tank effluent. Multiple processes within the leach field can attenuate dissolved CEC concentrations (summarized by Conn and Siegrist 2009).

Sorption of organic compounds to soil surfaces is affected by several key characteristics of the soil and of the CEC. The hydrophobicity of the CEC (indicated by the octanol-water partitioning coefficient, log K_{ow}) and the amount and content of organic matter within the soils control adsorption of CECs onto particulate organic matter, with more hydrophobic compounds (higher log K_{ow}) undergoing a higher degree of sorption. The pK_a (acid dissociation cnstant) and soil pH also can affect sorption by controlling the ionization state of the CEC; chemicals that have a net negative charge in soils are more likely to stay in solution since clays and other soil constituents also have a net negative charge. While Cape Cod soils are generally low in organic carbon content, transport of non-polar organic compounds was found to be related to organic carbon content of soils and log K_{ow} (Barber et al. 1988). Furthermore, leach field soils contain high levels of wastewater-derived organic carbon. Table 2 shows the log K_{ow} values for nine CECs; the two highly hydrophobic CECs (log K_{ow}>4), triclosan and nonylphenol, were found to have removal rates ≥80% (Table 4), and were modeled to show modest loading into Cape Cod ponds.

Microbial degradation, primarily in aerobic soils, is a key removal mechanism during wastewater treatment. Whereas the anaerobic conditions of a septic system provide limited removal, analogous to primary settling tanks in WWTPs, the aerobic soils of a leach field are analogous to the aerobic conditions of activated sludge and other biological stages of WWTPs (Conn and Siegrist 2009). CECs have a range of biodegradability based on their chemical structure, which can be predicted using computer programs such as BIOWIN (U.S. EPA 2000a), or on the basis of laboratory experiments. Actual biodegradation in the field can vary widely from predictions based on structure and on the biogeochemical conditions in the field, and depends on the microbial activity and community structure. The levels of dissolved oxygen were a key determinant of CEC persistence in a septic system plume; concentrations of several estrogens, pharmaceuticals, and caffeine in the anoxic portion of the plume were similar to those found in septic tank effluent, but dropped to non-detectable levels within aerobic portions of the plume (Swartz et al. 2006).

It is important to keep in mind that apparent removal of a specific CEC does not necessarily imply complete chemical breakdown. During biodegradation, partial breakdown of a parent compound can produce metabolites that result in apparent removal, since the parent compound is no longer detected by the analytical method. These "daughter" compounds may be structurally similar to the parent compounds and may revert back to the parent compound over time, or may persist in aquatic systems. In general, these degradation reactions are complex and the structures and potential toxicity of metabolites are poorly characterized for most CECs.

Modifications to the standard design of leach fields may further enhance CEC removal (summarized by Heufelder 2012a). CEC removal within leach fields can be enhanced by low pressure distribution in leach field lines, which distribute effluent more evenly throughout the entire leach field, promoting better contact between septic tank effluent and vadose zone soil surfaces and better aeration. By contrast, septic tank effluent from gravity-fed systems is often distributed from just a small portion of the leach lines. In addition, lower hydraulic loading rates (HLRs) can promote CEC removal. For instance, soil column experiments designed to mimic leach field conditions generally showed enhanced CEC removal as HLRs decreased from 30 cm/day to 1 cm/day (Teerlink et al. 2012b). Increasing the vertical separation between the bottom of the leach field and the water table can provide additional time and surface area for removal processes to occur, although the benefits may vary by chemical. In a study of a septic system serving an apartment building, caffeine and triclosan were removed to non-detectable concentrations within 60 cm of the infiltrative surface of the leach field, while concentrations of the more persistent EDTA and 4-nonylphenol continued to decrease down to 240 cm (Conn et al. 2010b). Studies conducted at the Massachusetts Alternative Septic System Test Center (MASSTC) have addressed how modifications to leach field design can significantly enhance CEC removal (Heufelder 2012a). For instance, drip dispersal systems, which distribute septic tank effluent through leach lines closer to the ground surface have been shown to provide a high degree of CEC removal, especially with the addition of air, likely due to a combination of enhanced microbial activity and sorption in the carbon-rich root zone (Heufelder 2012b). Beyond modifying leach field design, innovative/alternative onsite wastewater treatment system designs also may provide a high degree of removal for some CECs (Hinkle et al 2009). While some studies have shown that some types of advanced onsite systems can enhance removal over conventional systems, Zimmerman and Heufelder (2007) observed lower concentrations of

CECs in the leach fields of standard Title 5 systems than from a range of alternative systems, that include recirculating sand filters, aerobic treatment units, and peat treatment system.

For many CECs, functioning septic systems appear to substantially reduce CEC concentrations in discharges to groundwater. However, many septic systems do not function as designed, and this has profound implications for CEC discharges into groundwater. U.S. EPA estimates that 10-20% of septic systems are malfunctioning, and over half of septic systems are over 30 years old, which makes them more prone to malfunction (U.S. EPA 2005). Chalew (2006) summarized reasons for septic system failure, including high hydraulic loading rates that lead to anaerobic conditions in leach fields and infrequent septic tank pumping that can lead to shorter solids retention times in septic tanks and increased discharges of solids and biochemical oxygen demand into leach fields. Since CECs are more persistent in anaerobic groundwater (Swartz et al. 2006), septic tank effluent that reaches the water table or surface water body without extended residence time in aerated vadose zone soils may cause much higher CEC loadings than expected based on studies of functioning systems. Chalew (2006) proposed that testing groundwater concentrations of triclosan and caffeine, which are both effectively removed in leach fields, may be useful for identifying failing septic systems. Caffeine and triclosan were among the most frequently detected CECs in a nationwide survey of groundwater (Barnes et al. 2008).

Challenges in assessing CEC removal in septic systems

Our ability to characterize CEC concentrations and removal in septic system leach fields was limited by a number of factors. While dozens of studies have been conducted of CEC removal in WWTPs, fewer than 20 studies were available for septic systems. While WWTPs collect wastewater from thousands, even hundreds of thousands of households, providing a more integrated measure of wastewater composition across a population, septic systems often serve a single household or a small number of households. Therefore, the available studies may not necessarily provide a representative sampling of typical concentrations. CEC concentrations in raw wastewater tend to be less variable in treatment systems that serve larger populations (Teerlink et al. 2012a). This problem may be exacerbated for prescription pharmaceuticals and other CECs that are only used by a small portion of the population at any given time, for which we would expect to find most households with very low or non-detectable levels and a few households with relatively high concentrations. Our ability to quantitatively assess CEC concentrations in septic systems was also limited by relatively high reporting limits associated with the analytical methods used to analyzed the samples and by matrix effects that can lead to poor surrogate recovery.

CEC concentrations in raw wastewater can vary substantially depending on the source. Conn et al. (2006) observed that septic systems with non-residential sources tended to be have higher concentrations and more detected CECs than those serving residential sources, although those trends will depend on the uses for each specific chemical, and each type of source will have a unique CEC composition. Sources of wastewater include toilets, dish/clothes washing, bathing, faucets, and miscellaneous uses, and the relative contributions for each of these sources will differ between residential settings and other settings where septic systems are used, such as office buildings, campgrounds, restaurants (Conn and Siegrist 2009). For instance, wastewater from office buildings and restaurants may include relatively high levels of cleaning products (Conn and Siegrist 2009). Even the composition of blackwater (wastewater from toilets) differs between homes and non-residential settings, with higher urine:solid ratios expected in day use facilities (Hinkle et al. 2005).

Assessing CEC concentrations in the groundwater beneath a leach field is more challenging than collecting effluent samples from tanks and far fewer studies assess CEC concentrations after passing through a leach field. Most studies rely on installation of a lysimeter or well to collect groundwater samples, with the exception of the test systems at the MASSTC facility where the bottoms of leach fields are lined and an effluent collection system is in place. Furthermore, septic tank effluent that has passed through a leach field can be diluted by rain water and by existing water below the water table, and most studies do not account for this dilution. Conservative tracers can be used to characterize wastewater dilution in groundwater. Huntsman (2006) injected a pulse of bromide tracer into a leach field and estimated that the septic tank effluent was diluted by a factor of three by the time it reached a depth of 120 cm below the infiltrative surface. Katz (2010) used chloride concentrations to account for dilution and found that 15-25% of the apparent reduction in nitrogen from septic tank effluent to leach field lysimeters and wells was attributable to dilution.

Our ability to assess removal efficiencies within septic system leach fields is limited because, with the exception of soil column experiments, most field studies are not designed to measure removal efficiencies. The hydraulic residence time within a leach field is on the order of days, but samples of septic tank effluent and leach field effluent are typically collected at the same time, so the septic tank effluent and leach field samples do not necessarily correspond to each other. If CEC concentrations are highly variable in septic tank effluent, then apparent removal within the leach field may not reflect actual removal processes. Ideally, both septic tank effluent and leach field effluent would be sampled repeated over time to establish typical values, but the expense of CEC analyses likely precludes this type of in-depth study.

Additional chemical classes of concern

Hormones. The presence of endogenous (natural) and synthetic hormones in discharges from WWTP effluent and other wastewater sources has been associated with endocrine disruption in fish and other aquatic organisms within receiving water bodies (Jobling et al. 1998; Writer et al. 2010). The presence of hormones from wastewater can disrupt sensitive biochemical signaling in fish and other organisms. In a lake-wide experiment, addition of 5-6 ng/L of a synthetic estrogen (17α-ethinylestradiol) led to feminization of male fish and the crash of the native fathead minnow population (Kidd et al. 2007). Hormones are among the CECs that are being considered for potential future regulation in drinking water; the U.S. EPA included several hormones in their most recent Candidate Contaminant List (CCL3) and Unregulated Contaminant Monitoring Rule (UCMR3) contaminant list.

While some studies have evaluated hormone concentrations in septic tank effluent, little is known about removal efficiencies and typical concentrations associated with leach fields. Hormone concentrations in septic tank effluent range up to around tens to hundreds of ng/L, with maximum concentrations of 65 ng/L for estrone, 79 ng/L for 17β-estradiol, and 370 ng/L estriol (Stanford and Weinberg 2010). No studies directly measured hormones in leach field effluent, although Wilcox et al. (2009) measured estrogenic activity, a measure of the estrogen-mimicking strength of the mixture of chemicals in a sample, in effluent from single-pass sand filters and found up to 3.8 ng/L EEQ (estradiol equivalent concentration).

Concentrations of hormones in leach field effluent are expected to be low given their low concentrations in WWTP effluent and their high log K_{ow} values. In a compilation by Oulton et al. (2010), concentrations of 17β-estradiol, 17α-ethinylestradiol, and estriol were generally ≤5 ng/L in WWTP effluent, with somewhat higher concentrations observed for estrone. Our study of a septic system plume showed persistence of estrone and estradiol in anaerobic groundwater, but non-detectable concentrations in aerobic portions of the plume, suggesting substantial aerobic biodegradation (Swartz et al. 2006). However, we found detectable levels of four hormones in Cape Cod ponds, with maximum concentrations up to 3 ng/L estrone and 6.5 ng/L progesterone, levels that approached concentration associated with endocrine disruption in some fish species (Standley et al. 2008). These results suggest either greater persistence in some septic systems than expected, or discharges from failed or older septic systems that do not undergo full treatment in a leach field.

Perfluorinated chemicals. Perfluorinated chemicals (PFCs) are used in a range of consumer products, including food packaging, nonstick cookware, stain resistant textiles, paints and lubricants, and have numerous commercial and industrial applications. Concerns about their persistence in the environment and accumulation in the human body have led to the phase-out of some longer chain PFCs, such as PFOS and PFOA, and substitution with shorter-chain substitutes thought to be less likely to accumulate in the human body.

Our studies of public and private drinking water wells on Cape Cod showed that PFCs are prevalent in Cape Cod groundwater. Half of the public wells we tested contained detectable levels of PFOS, likely coming from a combination of domestic and non-residential sources (Schaider et al. 2010, 2014). Our private well study, in which we tested for a wider range of PFCs, showed the prevalence of several additional PFCs, including PFBS, PFHxS, and PFHxA (Schaider et al. 2011). Their abundance was strongly associated with an artificial sweetener, acesulfame, suggesting that domestic wastewater was the primary source of PFCs.

While PFC concentrations in WWTP effluent have been characterized, to our knowledge, no studies have assessed PFC effluent concentrations and removal efficiencies associated with onsite wastewater treatment. PFCs concentrations in WWTP effluent are on the order of tens to hundreds of ng/L (Sinclair and Kannan 2006; Ahrens 2011). PFCs concentrations are determined by a complex set of chemical reactions among related chemicals. During secondary treatment with activated sludge, concentrations of PFOS, PFOA, and several other PFCs were found to increase, likely through the breakdown of precursor compounds (Sinclair and Kannan 2006). While PFC concentrations may be higher in effluent from some WWTPs that receive discharges from industrial sources, we expect effluent from leach fields to be similar to concentrations from conventional secondary WWTPs that serve primarily residential areas; however, further study is needed to characterize PFC discharges from septic systems.

Implications for wastewater management on Cape Cod

Cape Cod communities are facing challenging decisions about the most effective approaches to address excessive nutrient loading into impaired coastal and freshwater systems. At the same time, increasing levels of nitrate in public water supplies (Cape Cod Commission 2009) and the presence of CECs in drinking water demonstrates that the Cape's growing population is impacting its drinking water quality. While public water supplies meet current federal drinking water standards, CECs may be regulated in drinking water in the future, so long-range planning should consider potential regulation. Furthermore, chemicals that are not regulated may be associated with adverse health effects. Drinking water supplies in areas served by private wells are also vulnerable, and private wells may be less protected and less extensively monitored than public wells. Minimizing wastewater impacts on drinking water will reduce exposures to CECs and may better protect public health. Priorities include minimizing current drinking water impacts by reducing CEC loading from septic systems and other wastewater treatment into recharge areas for drinking water wells and avoiding new discharges of treatment plant effluent into areas that recharge public and private drinking water wells.

This report provides an important first step for evaluating how changes to existing wastewater infrastructure could alter the cycling of CECs in the Cape Cod aquifer. From this review, we have a better understanding of typical CEC concentrations in effluent from septic systems. Combined with our compilation of CECs in WWTP effluent, we can begin to evaluate how proposed expansion of sewered areas could alter total mass loading and distribution of CEC inputs into the Cape aquifer. For instance, receiving water bodies, such as the Lewis Bay system and West Falmouth Harbor, and public supply well recharge areas may receive increased loading if proposed sewering expansion occurs, while there may be decreased CEC loading into areas that convert from onsite to centralized treatment. This study can provide key inputs for future fate and transport models in the Cape Cod aquifer that can consider sorption and degradation processes.

Beyond expanded sewer systems, a number of alternative treatment strategies are being considered in towns throughout Cape Cod that may offer more sustainable and less costly ways to address excessive nutrient loading. The Town of Falmouth has funded a series of pilot studies to evaluate alternative approaches to reducing nutrient concentrations in impacted receiving waters, including eco-toilets (composting and urine-diverting toilets), inlet widening, shellfish aquaculture, and reactive barriers. The Eco-Toilet Demonstration Project will subsidize 62 residents to install eco-toilets in their homes in order to evaluate changes in nitrogen concentrations in greywater (wastewater from non-toilet sources such as sinks and showers) following eco-toilet installation. Silent Spring Institute recently received funding from the Massachusetts Environmental Trust and private donations to test CECs in wastewater from homes taking part in the demonstration project. We hypothesize that installation of eco-toilets will substantially reduce greywater concentrations of pharmaceuticals and hormones that primarily enter wastewater through blackwater, but that concentrations of consumer product chemicals such as detergents and PFCs may actually increase as the overall volume of water use is reduced. Other options being considered such as inlet widening and reactive barriers will not reduce CEC concentrations in groundwater, but may lead to lower concentrations within coastal embayments.

Recommendations and next steps

- *Fate and transport modeling of CECs in Cape Cod groundwater.* Current models of groundwater movement in the Cape Cod aquifer can be used in conjunction with reactive transport modeling to predict the movement and attenuation of CECs. These models may better predict how proposed changes to wastewater management will affect vulnerable drinking water supplies and receiving waters and provide another metric for evaluating the costs and benefits of proposed wastewater treatment strategies.
- *Testing CECs in effluent from Cape Cod WWTPs.* Since the concentration of CECs in WWTP effluent is a function of the combination of treatment steps used and design parameters such as solids retention time, measuring CECs in the effluent from WWTPs on

Cape Cod will provide more accurate estimates of current loading into groundwater from these sources. In addition, wastewater on Cape Cod may have higher pharmaceutical concentrations than for the U.S. population as a whole due to its older population.

- *Testing perfluorinated chemicals in effluent from leach fields.* Our previous studies of public and private drinking water wells showed the prevalence of PFCs in Cape Cod groundwater, but little is currently known about typical PFC concentrations in effluents from leach fields. Additional work is also necessary to identify household sources for the most commonly-found PFCs, since their movement from household products into domestic wastewater is not well-characterized.

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Figure 1. Discharges of CECs into groundwater from septic systems.

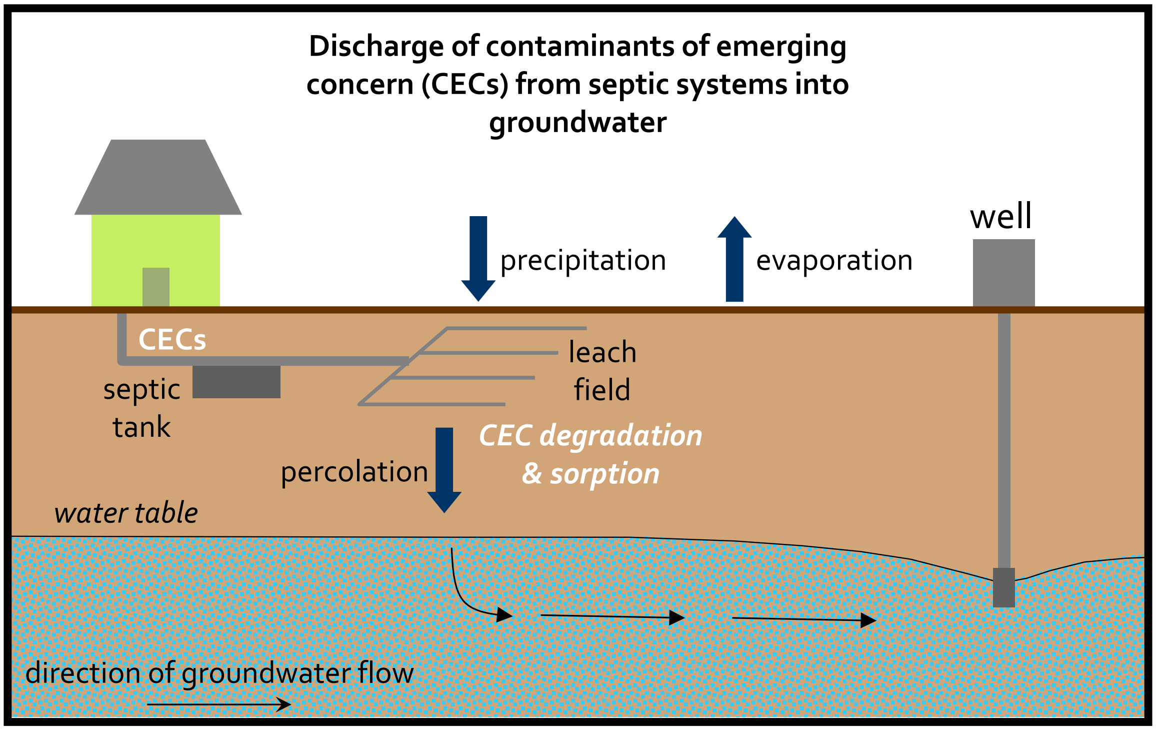


Figure 2. Map of Cape Cod areas modeled in this study
Base map of sewered and unsewered parcels generated using WatershedMVP (Cape Cod Commission 2013).

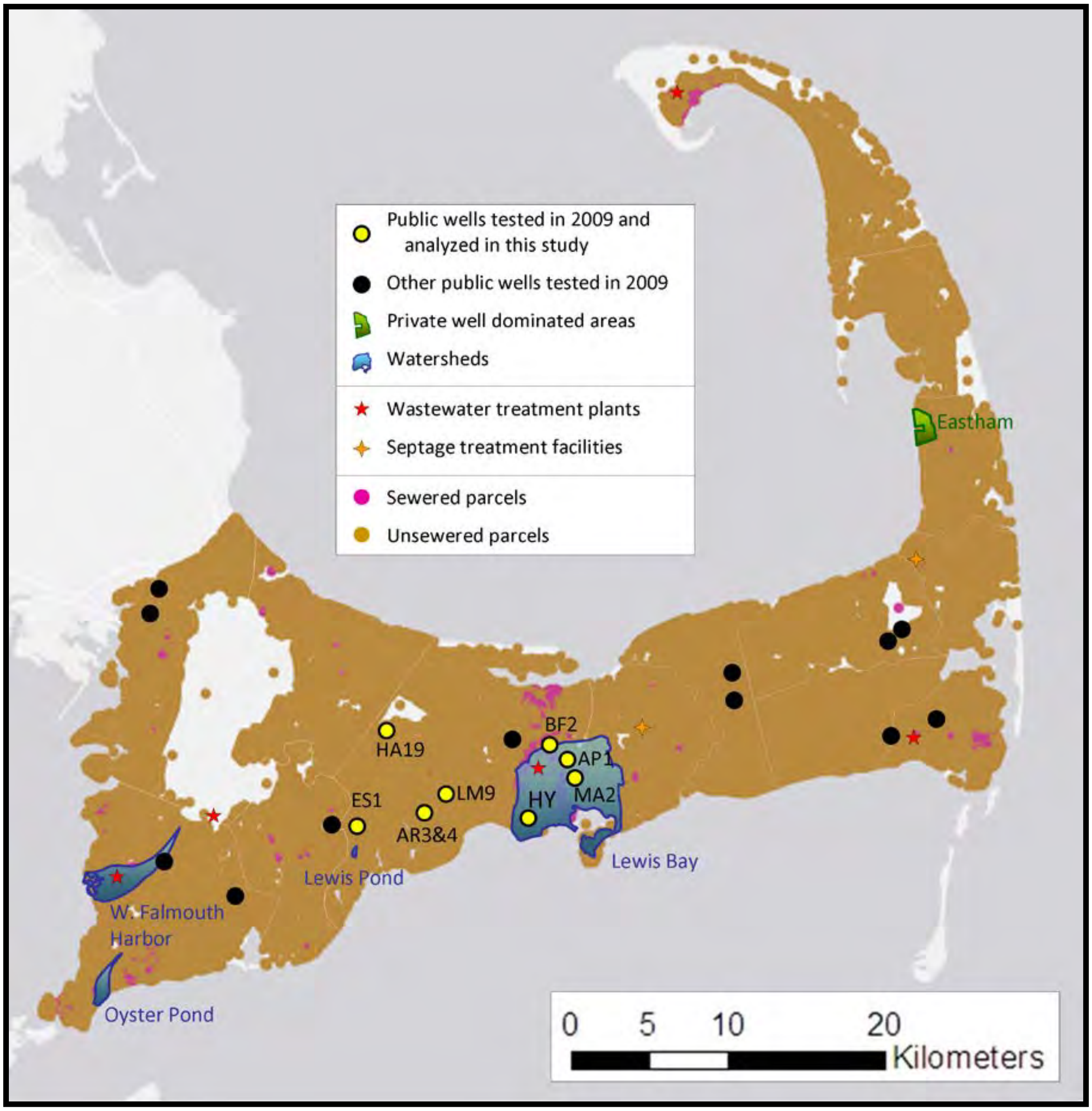
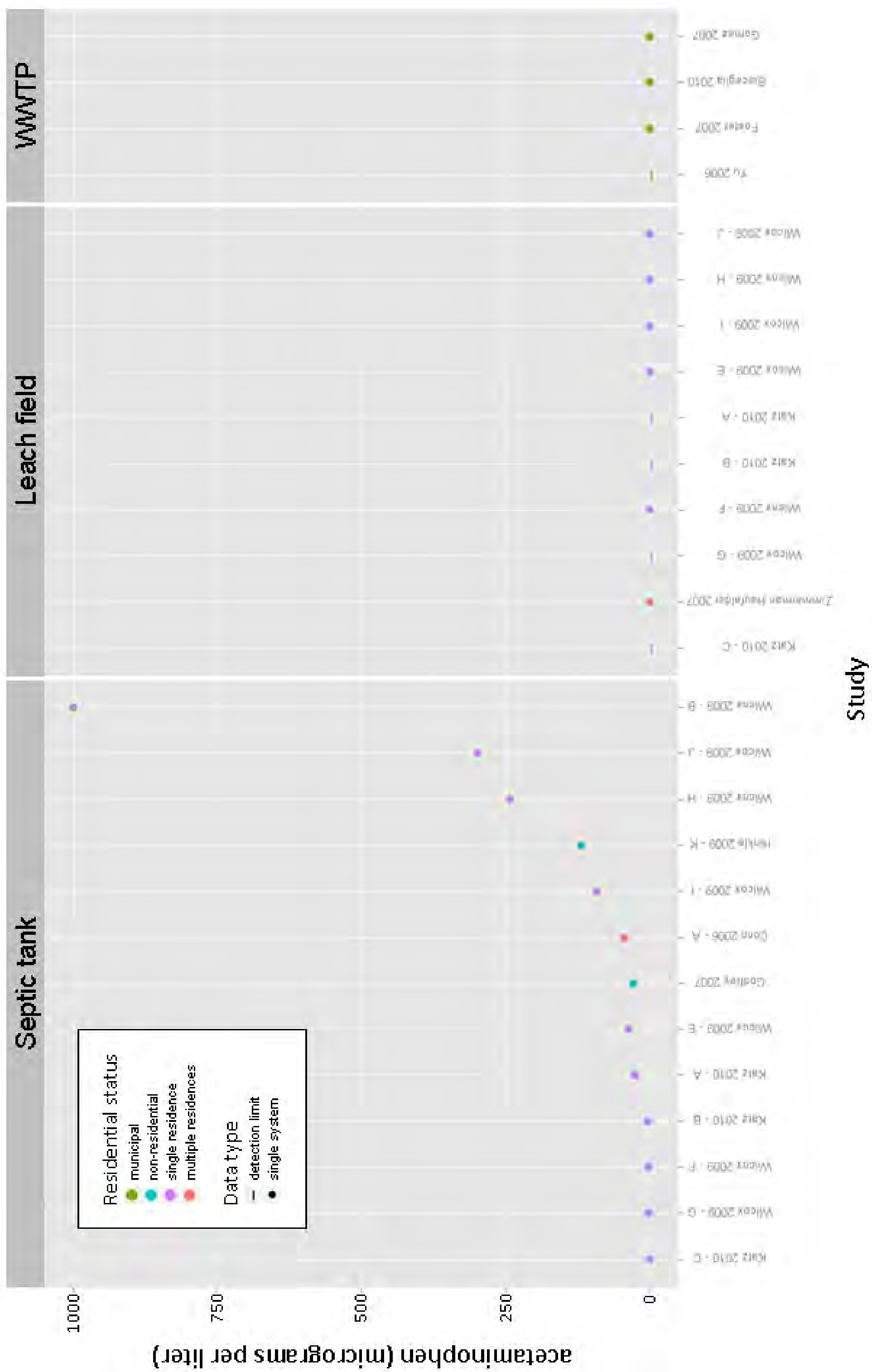
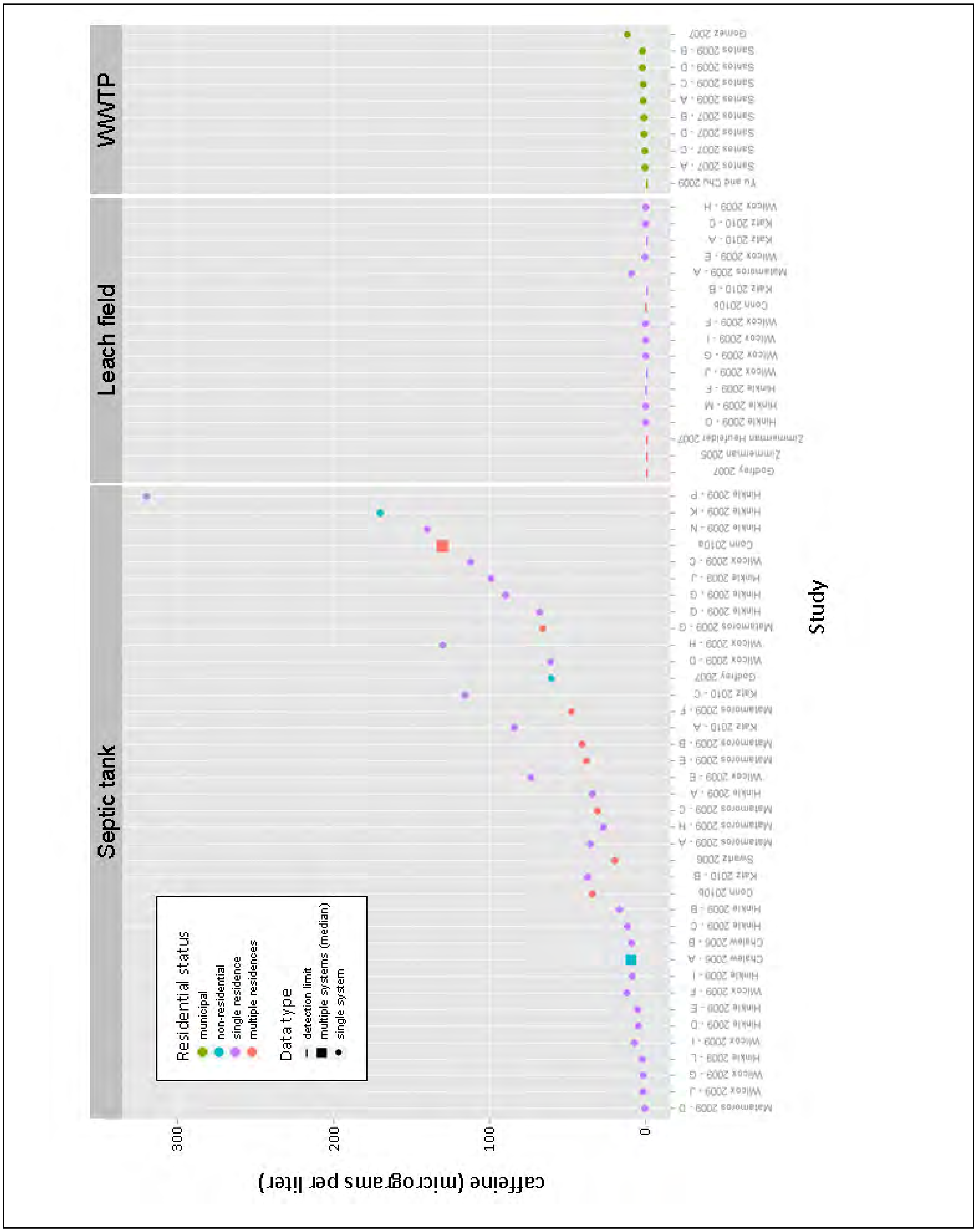


Figure 3. CEC effluent concentrations from septic tanks, leach fields, and WWTPs
Detection limits for samples with non-detectable concentrations are depicted with a line.

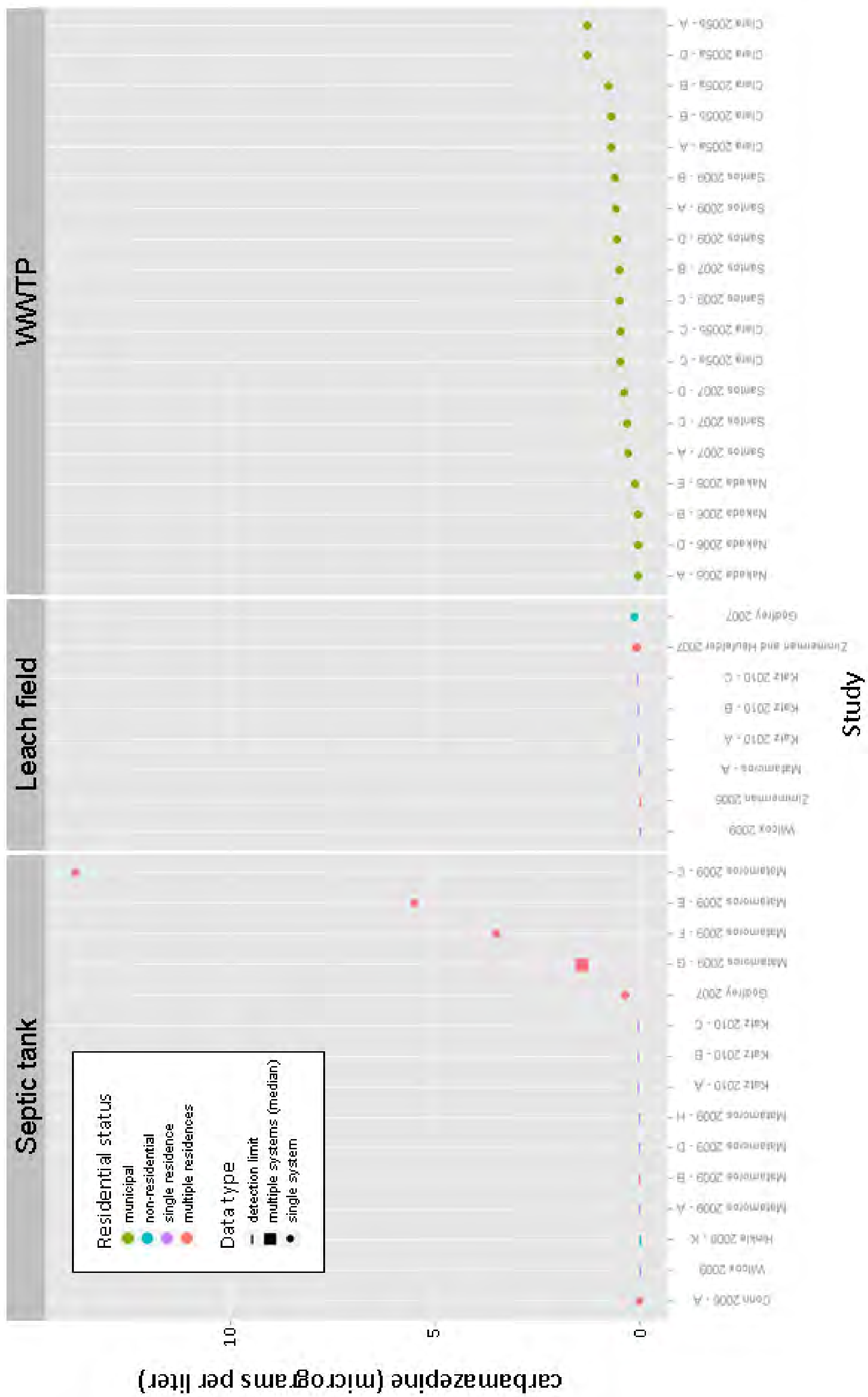
(a) acetaminophen



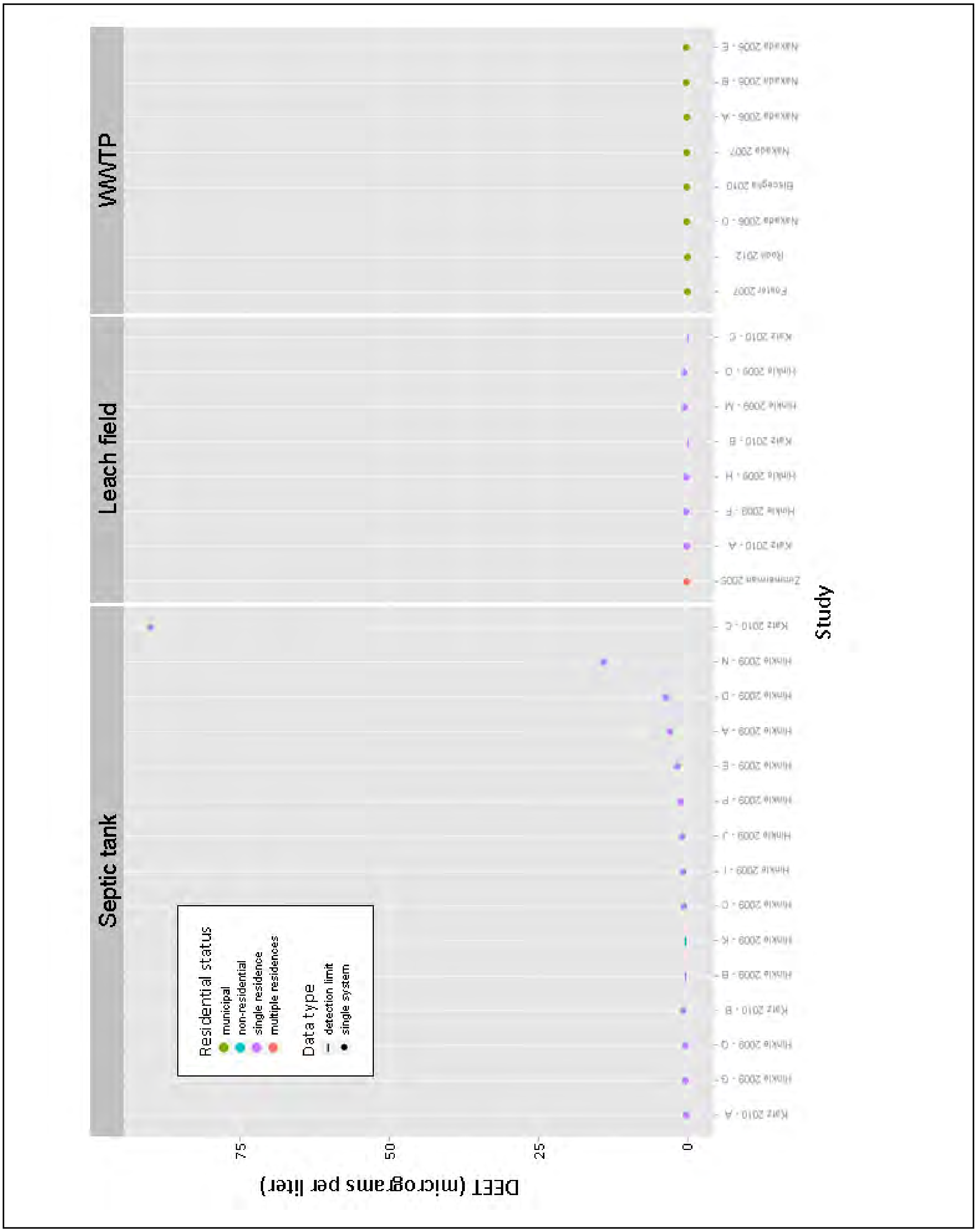
(b) caffeine


Septic tank
Leach field
WWTP
Study
caffeine (micrograms per liter)
Residential status
municipal
non-residential
single residence
multiple residences
Data type
detection limit
multiple systems (median)
single system

(c) carbamazepine

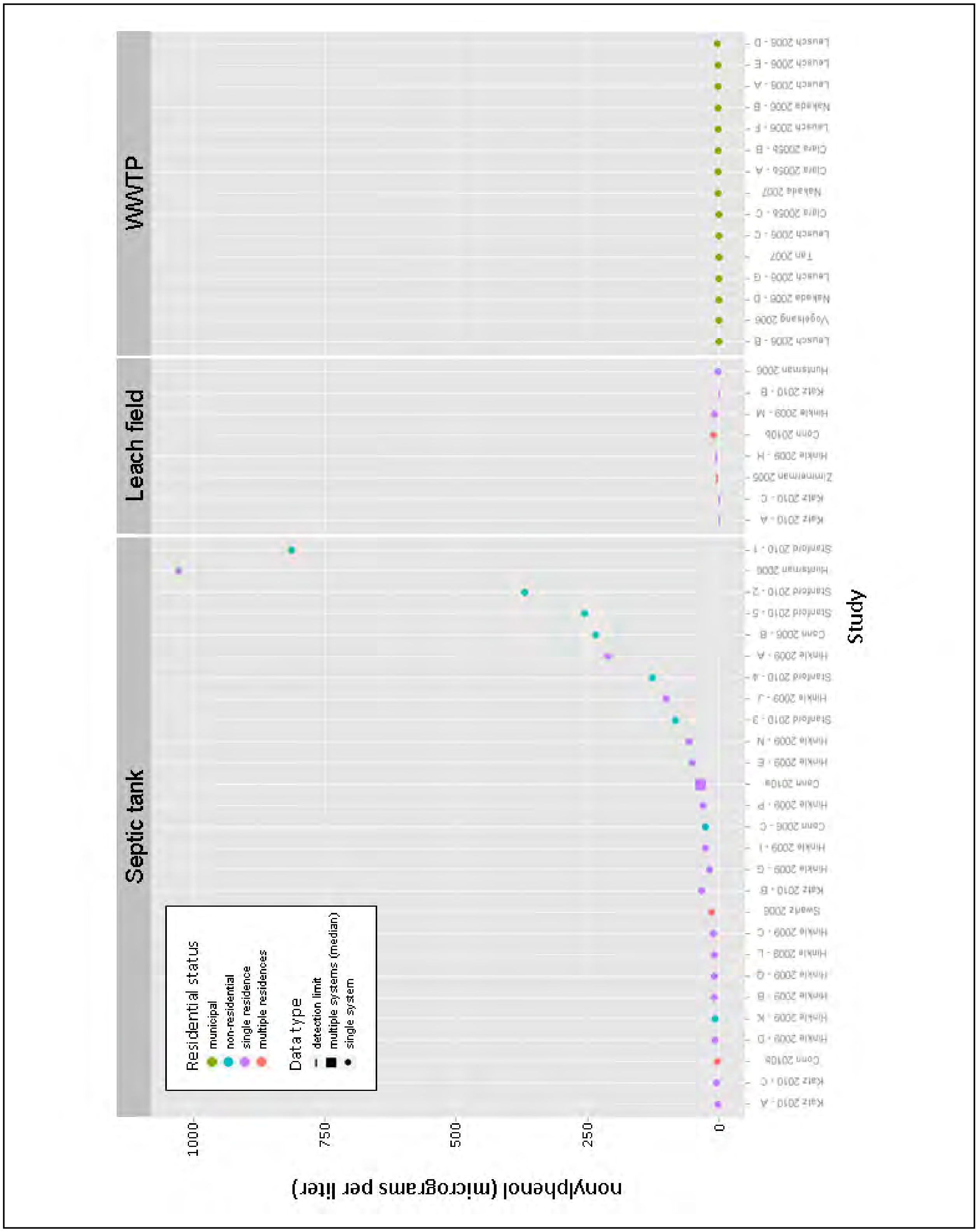


(d) DEET

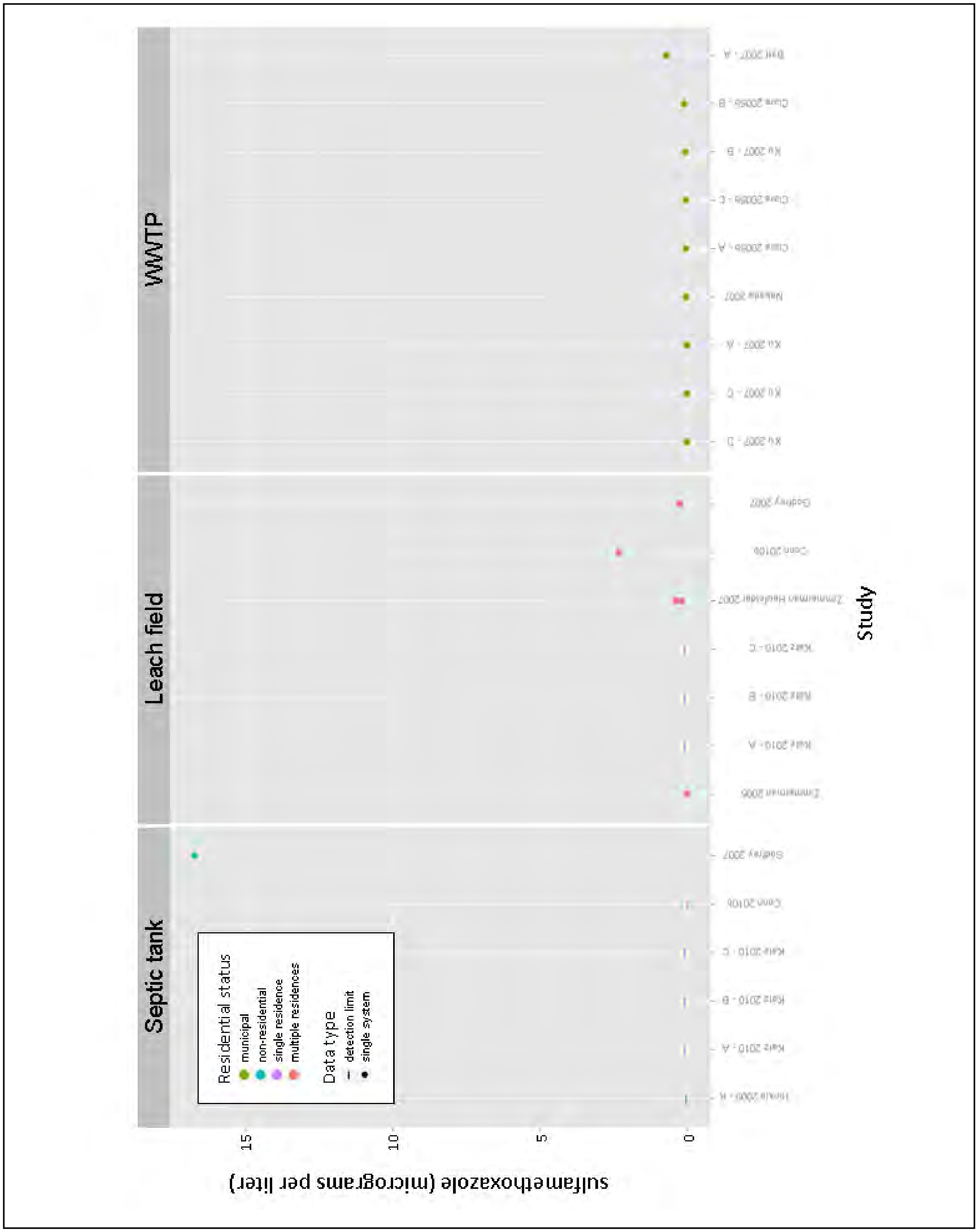


Septic tank
Leach field
WWTP
DEET (micrograms per liter)
0
25
50
75
Study
Residential status
municipal
non-residential
single residence
multiple residences
Data type
detection limit
single system
Katz 2010 - A
Hinkle 2009 - G
Hinkle 2009 - Q
Katz 2010 - B
Hinkle 2009 - B
Hinkle 2009 - K
Hinkle 2009 - C
Hinkle 2009 - I
Hinkle 2009 - J
Hinkle 2009 - P
Hinkle 2009 - E
Hinkle 2009 - A
Hinkle 2009 - D
Hinkle 2009 - N
Katz 2010 - C
Zimmerman 2005
Katz 2010 - A
Hinkle 2009 - F
Hinkle 2009 - H
Katz 2010 - B
Hinkle 2009 - M
Hinkle 2009 - O
Katz 2010 - C
Foster 2007
Rodi 2012
Nakada 2006 - D
Bisceglia 2010
Nakada 2007
Nakada 2006 - A
Nakada 2006 - B
Nakada 2006 - E

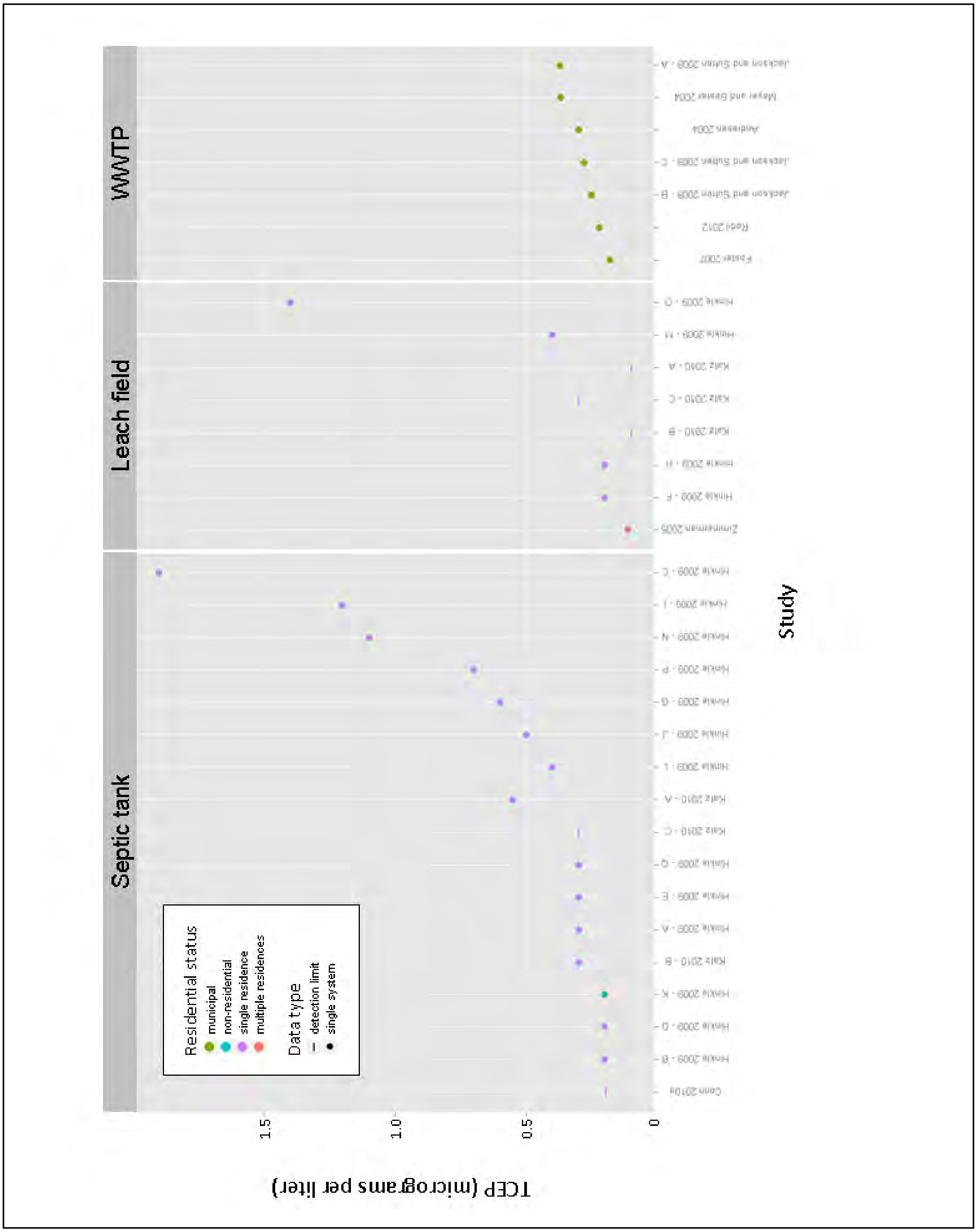
(e) nonylphenol



(f) sulfamethoxazole

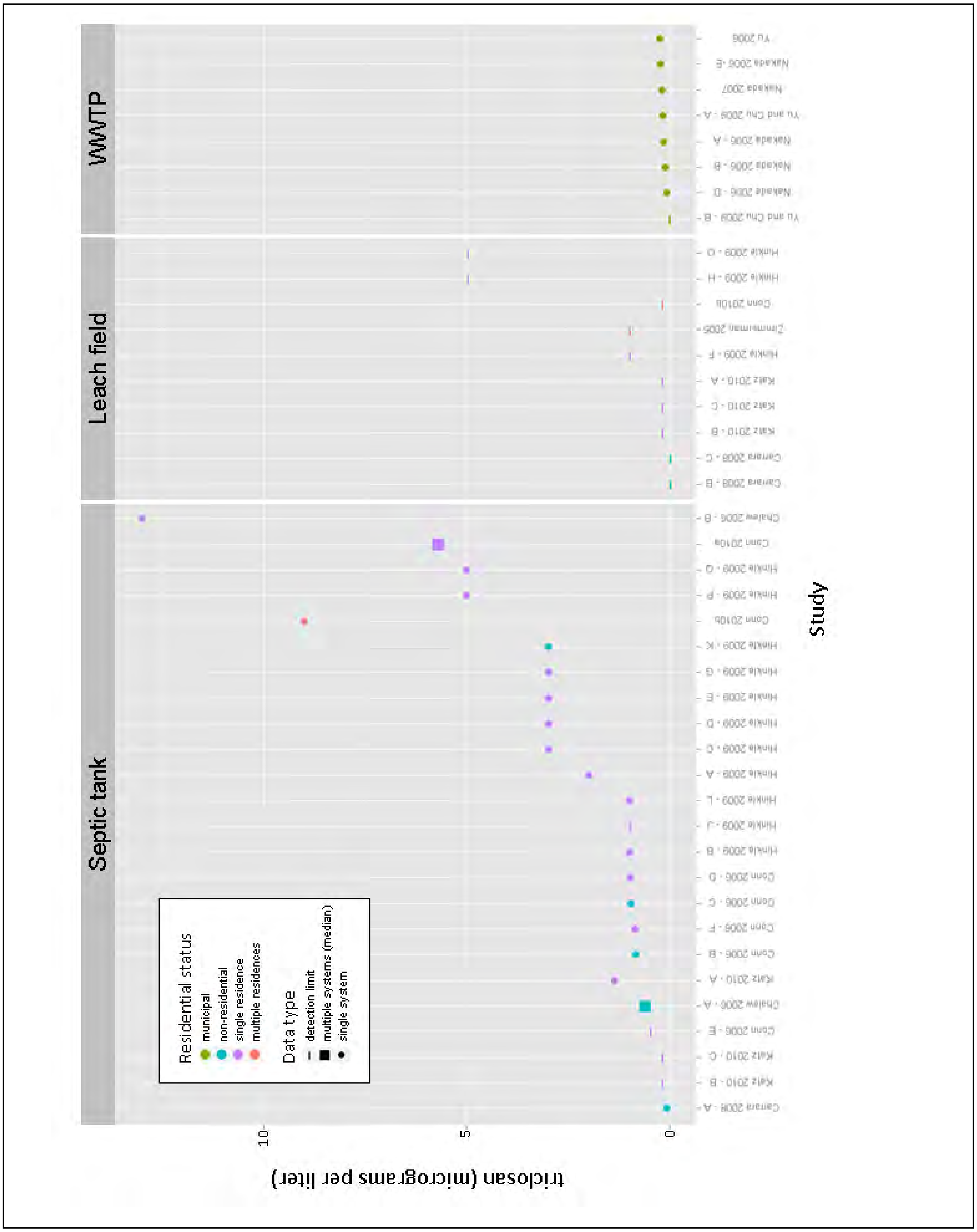


(g) TCEP



Septic tank
Leach field
WWTP
Residential status
municipal
non-residential
single residence
multiple residences
Data type
detection limit
single system
Study
TCEP (micrograms per liter)
1.5
1.0
0.5
0

(h) triclosan



Septic tank
Leach field
WWTP
Residential status
municipal
non-residential
single residence
multiple residences
Data type
detection limit
multiple systems (median)
single system
triclosan (micrograms per liter)
Study
0
5
10
Carrara 2008 - A
Katz 2010 - B
Katz 2010 - C
Conn 2006 - E
Chalew 2006 - A
Katz 2010 - A
Conn 2006 - B
Conn 2006 - F
Conn 2006 - C
Conn 2006 - D
Hinkle 2009 - B
Hinkle 2009 - J
Hinkle 2009 - L
Hinkle 2009 - A
Hinkle 2009 - C
Hinkle 2009 - D
Hinkle 2009 - E
Hinkle 2009 - G
Hinkle 2009 - K
Conn 2010b
Hinkle 2009 - P
Hinkle 2009 - Q
Conn 2010a
Chalew 2006 - B
Carrara 2008 - B
Carrara 2008 - C
Katz 2010 - B
Katz 2010 - C
Katz 2010 - A
Hinkle 2009 - F
Zimmerman 2005
Conn 2010b
Hinkle 2009 - H
Hinkle 2009 - O
Yu and Chu 2009 - B
Nakada 2006 - D
Nakada 2006 - B
Nakada 2006 - A
Yu and Chu 2009 - A
Nakada 2007
Nakada 2006 - E
Yu 2006

(i) trimethoprim

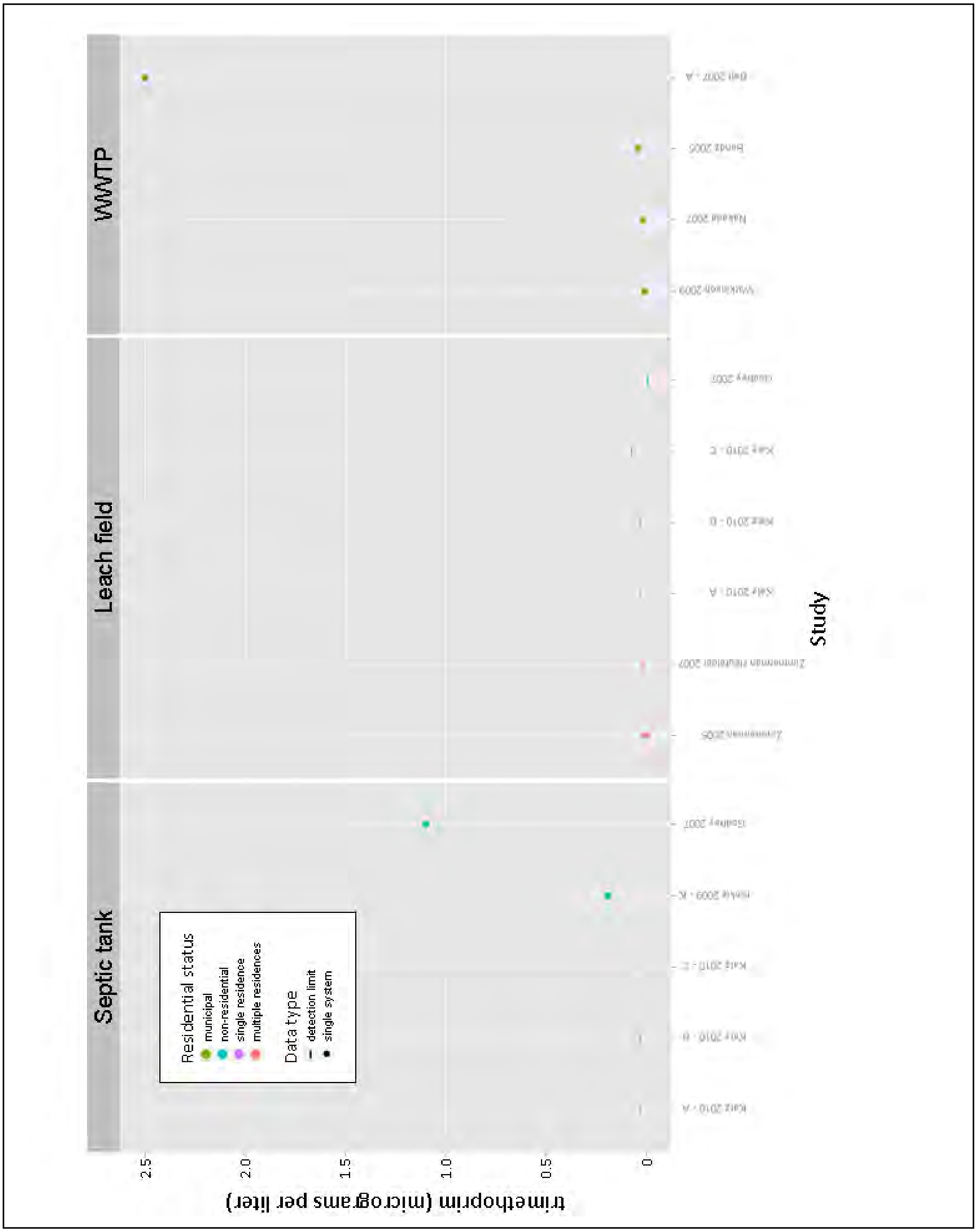


Table 1. Summary of septic system studies included in compilation

Study	Septic tank effluent (STE), number of systems tested	Leach field effluent (LFE), number of systems tested	Advanced treatment systems tested	Number of people or residences served	Location of study	Number of CECs analyzed	Ancillary parameters reported	Notes
Carrara et al. 2008	2 systems, both tested twice	3 systems, tested 1.5-6 m below leachfield lines	None	2 seasonal sites: 200 campgrounds, 2000 visitors	Ontario, Canada	12	pH, NO_3^-, NH_3, SO_4^{2-}, Cl, Fe, Mn, CH_4	For STE, only included 1 of 4 samples with surrogate recovery >50%, except for ibuprofen, for which corrected values were used. Excluded blackwater only system. For LFE, included only shallowest samples under leach field lines (~3m).
Chalew 2006	1 household system, 2 advanced treatment systems	No	Dual recirculating sand filter (SF), anaerobic wetland, greenhouse	individual household, office building (60 people) and high school (400 people)	North Carolina, USA	2	None	Values included from 3 systems
Conn et al. 2006	30	No	Aerobic biofilter, subsurface constructed wetland	16 residential sources (single, multi-family), 14 non-residential	Colorado, USA	24 in main study; additional CECs tested in 5 systems	Specific conductivity (SpC), NH_3, TDS, cBOD	Data in summary table excluded because influent and effluent combined. Data only used from systems collected from graphs and within text.

Conn et al. 2010a	6 systems, each sampled 1-3 times	No	No	Single family homes	Florida, Colorado, Minnesota, USA	20	DOC	Includes information on household usage of pharmaceuticals and personal care products
Conn et al. 2010b	1 system, effluent from series of 2 tanks	1 system tested at 60, 120 and 240 cm, at 2 hydraulic loading rates	Textile biofilters	8-unit apartment complex at university	Colorado, USA	7	pH, alkalinity, DOC, NH_3, NO_3^-	For LFE, included data for 2 cm/day, closest to Title 5 (3 cm/day)
Godfrey et al. 2007	1 system, sampled twice in 1 week	1 system, tested 200 cm	No	High school (350 students and staff)	Montana, USA	22	pH, DO, SpC (from prior study of groundwater)	For LFE, included groundwater samples immediately under leach lines only
Hinkle et al. 2005	29, including 28 from residential sources	Lysimeter samples collected 30 cm below leach lines	Recirculating filters, aeration, SF	individual homes, one senior center	Oregon	63	DO, SpC, temperature, pH, NO_3^-, NO_2^-	For STE, included only non-recirculating systems
Huntsman et al. 2006	1 system, repeated tested over 13 months	1 system, tested at 120 cm below land surface	No	Single family home	Ohio, USA	5 individual CECs or families of CECs (e.g., NPE3-16)	SpC, redox potential, pH, temperature	Daily loading into septic tank equivalent to 3 loads of laundry per day
Katz et al. 2010	3 systems, each sampled 3 times in 7 months	3 systems, tested ~100 cm below land surface	No	Single family homes, 2-4 people each	Florida, USA	35	DO, pH, temperature, NH_3, NO_3^-, NO_2^-, DOC, phosphate	

Matamoros et al. 2009	13 systems, sampled once or twice in 3 months	1 non-recirculating sand filter included as surrogate	Compact biofilters, biological SF, constructed wetlands	4 to 280 people	Denmark	13	TSS, BOD, NH_3, DO	Included only 8 non-recirculating systems
Stanford and Weinberg 2010	5 systems, each sampled 1-6 times.	No	SF, aerobic and anaerobic wetlands, vegetated sand filters, green-house irrigation beds, UV/chlorination	Non-residential: office building, schools, girls' dormitory	North Carolina, USA	5, plus estrogenic activity		
Swartz et al. 2006	1 system sampled twice in one month	No	No	1 main house and 4 cottages	Cape Cod, Massachusetts, USA	14	NH_3, NO_3, DO, SpC, Boron, DO, Fe^{2+}, Fe_{total}, HCO_3^-	For LFE, excluded groundwater samples not below leach lines.
Teerlink et al. 2012b	No	Laboratory sand columns, 30 cm in length	no	Synthetic wastewater	Laboratory	17	NH_3, NO_3^-, DOC	Used only for removal rates; synthetic wastewater may not reflect actual concentrations. Included data for 4 cm/day wastewater loading rate.
Wilcox et al. 2009	15 resid. systems, 9 sampled once, 6 sampled twice	7 single pass sand filter systems	Suspended growth aerobic treatment, SF	Individual households	Wisconsin, USA	13, plus estrogenic activity		Included STE samples prior to advanced treatment steps. Single pass sand filters included as LF surrogate.

Zimmerman 2005	no	1 standard Title 5 system	Recirculating SF	Coast Guard housing and prison	Massachusetts, USA	85	NO_3^-	Samples collected from experimental septic system at Mass. Alternative Septic System Test Center
Zimmerman and Heufelder 2007	no	3 systems: two with 150 cm sand and one with 60 cm sand (control system)	Aerobic treatment, recirculating filter with peat, single pass filter with foam, sulfur-filled filter with aerobic treatment, recirculating SF	Coast Guard housing and prison	Massachusetts, USA	13		See Zimmerman 2005

Table 2. Chemical information for CECs included in the current study.
Octanol-water partitioning coefficients (log K_{ow}) were estimated using KOWWIN v1.68 (U.S. EPA 2000b) and indicate the degree of expected hydrophobicity (values over 4 indicate very hydrophobic compounds). Expected removal efficiencies were based on removal during conventional activated sludge treatment (reviewed by Oulton et al. 2010; U.S. EPA 2010). ND = not detected. "--" means not tested.

Chemical	**CAS number**	**log K_{ow}**	**Main uses**	**Maximum concentrations in Cape Cod studies**		
				20 public wells	20 private wells	6 ponds
Well removed (>80% removal in WWTPs)						
acetaminophen	103-90-2	0.27	pain reliever	*ND (<5 ng/L)*	*ND (<2.3 ng/L)*	*ND (<10 ng/L)*
caffeine	58-08-2	0.16	stimulant	*ND (<10 ng/L)*	*ND (<10 ng/L)*	*ND (16 ng/L)*
nonylphenol	84852-15-3	5.77-5.99	detergent metabolite	20 ng/L (estimated)	*ND (<18 ng/L)*	--
triclosan	3380-34-5	4.66	anti-microbial	*ND (<50 ng/L)*	*ND <3 ng/L)*	*ND (<16 ng/L)*
Moderately removed (50-80% removal in WWTPs)						
DEET	134-62-3	2.26	insect repellent	6 ng/L	4 ng/L	*ND (<25 ng/L)*
sulfamethoxazole	723-46-6	0.48	antibiotic	113 ng/L	60 ng/L	2.2 ng/L
trimethoprim	738-70-5	0.73	antibiotic	0.7 ng/L	1 ng/L	11 ng/L
Poorly removed (<50% removal in WWTPs)						
carbamazepine	298-46-4	2.25	anti-convulsant	72 ng/L	62 ng/L	2.4 ng/L
TCEP	115-96-8	1.63	flame retardant, plasticizer	20 ng/L	*ND (<1.7 ng/L)*	--

Table 3. Cape Cod areas modeled in this study.
Testing for CECs in public wells was conducted in 2009 (Schaider et al. 2010), and testing for CECs in ponds was conducted in 2007 (Standley et al. 2008). Calculations for percentage sewered parcels and percentage residential parcels are based on currently developed parcels. Airport 1, BFD2 and Maher 2 all share same ZOC and cannot be distinguished in CommunityViz analyses.
-- = no CEC testing.

Region		Area (acres)	% sewered parcels	% residential parcels	CEC testing results
Whole Cape		253126	3.3%	88%	
Public wells (with abbreviation and water district)					
Airport 1 (AP1) (Hyannis)	ZOC Zone 2	107 3960	13% 53%	0% 47%	3 CECs detected
Arena 3&4 (AR3&4) (C-O-MM)	ZOC Zone 2	82 2085	0.8% 0.1%	96% 93%	3 CECs detected
BFD2 (BF2) (Barnstable)	ZOC Zone 2	125 3960	38% 53%	48% 47%	3 CECs detected
Electric Station 1 (ES1) (Cotuit)	ZOC Zone 2	110 335	0% 0%	87% 88%	4 CECs detected
Harrison GP 19 (GP19) (C-O-MM)	ZOC Zone 2	296 1312	0% 0%	93% 96%	0 CECs detected
Hyannisport (HY) (Hyannis)	ZOC Zone 2	378 1058	18% 22%	94% 94%	12 CECs detected
Lumbert Mill 9 (LM9) (C-O-MM)	ZOC Zone 2	196 1325	0% 0%	87% 97%	10 CECs detected
Maher 2 (MA2) (Hyannis)	ZOC Zone 2	582 3960	32% 53%	21% 47%	8 CECs detected

Private well areas				
Eastham (near Campground Beach)	307	0%	99%	--
Watersheds				
Lewis Bay system (Barnstable, Yarmouth)	8759	27%	83%	--
West Falmouth Harbor (Falmouth)	1674	0.1%	82%	--
Lewis Pond (Barnstable)	60	0%	82%	6 CECs detected
Oyster Pond (Falmouth)	403	0%	90%	6 CECs detected

Table 4. CEC effluent concentrations from septic tanks, leach fields and WWTPs.
All concentrations reported in µg/L (micrograms per liter, or parts per billion). For the three prescription pharmaceuticals, only data from septic systems serving multiple residences and non-residential sources were considered. Leach field samples include both observed values and predicted values based on septic tank effluent concentrations and median percent removal in leach fields. Median concentrations reported to one significant digit to emphasize approximate nature of the estimates. N = number of systems used to generate estimates of median concentrations. n.d. = not detected. * indicates predicted value.

	Concentration in septic tank effluent			Concentration in leach field effluent			Percent removal in leach fields			Concentration in WWTP effluent		
	median	**maximum**	**N**	**median**	**maximum**	**N**	**median**	**range**	**N**	**median**	**maximum**	**N**
Pharmaceuticals												
acetaminophen	40	1000	13	0.1	4*	15	>99	98 to >99.9	9	0.1	0.22	4
carbamazepine	0.9	14	8	0.08	9*	11	40	10 to 60	2	0.5	1.3	19
sulfamethoxazole	0.03	29	3	0.2	7	6	40	0 to >95	3	0.1	0.7	7
trimethoprim	0.6	1.5	2	0.01	0.06*	5	70	33 to >99.9	2	0.03	2.5	4
Other CECs												
caffeine	40	850	38	0.1	18	41	>99	50 to >99.9	16	1	12	10
DEET	1	90	16	0.2	0.7*	17	80	0 to >99	8	0.1	0.26	8
nonylphenol	30	810	26	7	200*	26	80	0 to >99.9	6	0.3	2.1	15
TCEP	0.3	1.9	17	0.2	1.4	18	30	0 to 80	7	0.3	0.37	7
triclosan	1.2	57	24	0.1	2*	25	90	70 to >95	4	0.2	0.25	8

Table 5. Wastewater flows and nitrogen loading into Cape Cod aquifer.
Annual discharges of wastewater from septic systems and WWTPs (in mgy, millions of gallons per year) and loading of total nitrogen (in kg/y, kilograms per year) into Cape aquifer areas. Public well nitrate concentrations were provided by Damon Guterman, MassDEP. Annual average nitrate concentrations were calculated for wells tested more than once per year.

		wastewater discharges		total nitrogen loading		2012 nitrate concentrations in public wells
		mgy	mgy/mi^2	kg/y	kg/mi^2/y	mg/L
Whole Cape		10,000	25	920,000	2300	
Public wells						
Airport 1	ZOC	0.28	1.7	28	170	0.22
(Hyannis)	Zone 2	34	5.5	3,000	500	
Arena 3&4	ZOC	8.0	63	800	6,000	2.8
(C-O-MM)	Zone 2	110	35	10,000	3,000	
BFD2 (BF2)	ZOC	2.3	12	200	1,000	0.66
(Barnstable)	Zone 2	34	5.5	3,000	500	
Electric Station 1	ZOC	5	29	510	3,000	1.6
(Cotuit)	Zone 2	14	26	1,200	2,300	
Harrison GP 19	ZOC	8.2	18	830	1,800	<0.1
(C-O-MM)	Zone 2	63	31	6,400	3,100	
Hyannisport	ZOC	43	73	3,800	6,400	4.4
(Hyannis)	Zone 2	290	180	10,000	6,300	
Lumbert Mill 9	ZOC	11	38	1,200	3,800	4.0
(C-O-MM)	Zone 2	95	46	9,600	4,600	
Maher 2	ZOC	6.4	7.1	650	720	0.53
(Hyannis)	Zone 2	34	5.5	3,000	480	
Private well areas						
Eastham		47	99	4,700	9,800	
Watersheds						
Lewis Bay system		1,100	79	60,000	4,400	
West Falmouth Harbor		180	69	7,700	3,000	
Lewis Pond		0.81	8.6	80	860	
Oyster Pond		10	16	1,000	1,600	

Table 6. CEC loading into Cape Cod aquifer.
Annual loading per unit time (in grams per year) and annual loading per unit time per area (in grams per square mile per year). These loading estimates are shown with just one significant digit to emphasize the approximate nature of these calculations.

Prescription pharmaceuticals

		carbamazepine		sulfamethoxazole		trimethoprim	
		g/y	g/mi²/y	g/y	g/mi²/y	g/y	g/mi²/y
Whole Cape		4,000	10	7,000	20	400	1
Public wells							
Airport 1	ZOC	0.1	0.5	0.2	1.0	0.01	0.06
(Hyannis)	Zone 2	20	3	20	4	2	0.3
Arena 3&4	ZOC	2	20	6	50	0.3	2
(C-O-MM)	Zone 2	30	10	90	30	4	1
BFD2 (BF2)	ZOC	0.7	4	2	9	0.09	0.4
(Barnstable)	Zone 2	20	3	20	4	2	0.3
Electric Station 1	ZOC	2	9	4	20	0.2	1
(Cotuit)	Zone 2	4	8	10	20	0.5	1
Harrison GP 19	ZOC	2	5	6	10	0.3	0.7
(C-O-MM)	Zone 2	20	9	50	20	2	1
Hyannisport	ZOC	20	40	30	50	2	4
(Hyannis)	Zone 2	400	200	100	70	20	10
Lumbert Mill 9	ZOC	3	10	9	30	0.4	1
(C-O-MM)	Zone 2	30	10	70	40	4	2
Maher 2	ZOC	2	2	5	6	0.2	0.3
(Hyannis)	Zone 2	20	3	20	4	2	0.3
Private well areas							
Eastham		10	30	40	80	2	4
Watersheds							
Lewis Bay system		1,000	90	500	40	80	6
West Falmouth Harbor		300	100	60	20	20	6
Lewis Pond		0.2	3	0.6	7	0.03	0.30
Oyster Pond		3	5	8	10	0.40	0.6

Other CECs

		acetaminophen		caffeine		DEET	
		g/y	g/mi^2/y	g/y	g/mi^2/y	g/y	g/mi^2/y
Whole Cape		4,000	10	9,000	20	6,000	10
Public wells							
Airport 1	ZOC	0.1	0.7	0.1	0.8	0.2	0.9
(Hyannis)	Zone 2	10	2	40	7	20	3
Arena 3&4	ZOC	3	30	4	30	5	40
(C-O-MM)	Zone 2	50	10	50	20	60	20
BFD2 (BF2)	ZOC	1	5	1	5	1	7
(Barnstable)	Zone 2	10	2	40	7	20	3
Electric Station 1	ZOC	2	10	2	10	3	20
(Cotuit)	Zone 2	6	10	6	10	8	10
Harrison GP 19	ZOC	3	8	4	8	5	10
(C-O-MM)	Zone 2	30	10	30	10	40	20
Hyannisport	ZOC	20	30	60	90	20	40
(Hyannis)	Zone 2	100	60	1,000	700	100	90
Lumbert Mill 9	ZOC	5	20	5	20	7	20
(C-O-MM)	Zone 2	40	20	40	20	50	30
Maher 2	ZOC	3	3	3	3	4	4
(Hyannis)	Zone 2	10	2	40	7	20	3
Private well areas							
Eastham		20	40	20	50	30	60
Watersheds							
Lewis Bay system		400	30	3,000	300	500	40
West Falmouth Harbor		60	20	700	300	90	30
Lewis Pond		0.3	4	0.4	4	0.5	5
Oyster Pond		4	7	5	8	6	9

Other CECs

		nonylphenol		TCEP		triclosan	
		g/y	g/mi²/y	g/y	g/mi²/y	g/y	g/mi²/y
Whole Cape		200,000	60	8,000	20	5,000	10
Public wells							
Airport 1	ZOC	7	40	0.2	1	0.1	0.8
(Hyannis)	Zone 2	700	100	30	4	20	3
Arena 3&4	ZOC	200	2,000	6	50	4	30
(C-O-MM)	Zone 2	3,000	900	80	30	50	20
BFD2 (BF2)	ZOC	60	300	2	9	1	5
(Barnstable)	Zone 2	700	100	30	4	20	3
Electric Station 1	ZOC	100	800	4	20	2	10
(Cotuit)	Zone 2	300	700	10	20	6	10
Harrison GP 19	ZOC	200	500	6	10	4	8
(C-O-MM)	Zone 2	2,000	700	50	20	30	10
Hyannisport	ZOC	900	2,000	30	60	20	40
(Hyannis)	Zone 2	3,000	2,000	300	200	200	100
Lumbert Mill 9	ZOC	300	1,000	9	30	5	20
(C-O-MM)	Zone 2	2,000	1,000	70	30	40	20
Maher 2	ZOC	200	200	5	5	3	3
(Hyannis)	Zone 2	700	100	30	4	20	3
Private well areas							
Eastham		1,000	3,000	40	70	20	50
Watersheds							
Lewis Bay system		10,000	1,000	900	70	600	40
West Falmouth Harbor		1,000	600	200	60	100	40
Lewis Pond		20	200	0.6	7	0.4	4
Oyster Pond		300	400	8	10	5	8

APPENDICES

APPENDIX 1: COMPLETE LIST OF CECS INCLUDED IN COMPILATION

N = number of systems tested (may include multiple systems from one study)
maximum = highest concentration in micrograms per liter (µg/L)
log K_{ow} = octanol-water partitioning coefficient (logarithm)
n.d. = not detected above reporting limit in any study
-- = not tested

Chemical	CAS number	log K_{ow}	Septic tank effluent		Leach field effluent	
			N	maximum	N	maximum
Pharmaceuticals – antibiotics						
sulfamethoxazole	723-46-6	0.48	6	17	8	2.3
trimethoprim	738-70-5	0.73	5	1.1	7	n.d.
Pharmaceuticals – prescription (not antibiotics)						
carbamazepine	298-46-4	2.25	29	14	23	0.14
diclofenac	15307-86-5	4.02	9	0.70	3	0.15
gemfibrozil	25812-30-0	4.77	8	0.015	3	0.04
naproxen	22204-53-1	3.10	15	150	3	0.18
Non-prescription pharmaceuticals and other pharmaceutically-active compounds						
acetaminophen	103-90-2	0.27	13	1000	11	1.3
caffeine	58-08-2	0.16	44	850	19	9.5
cotinine	486-56-6	0.34	17	51	11	0.03
ibuprofen	15687-27-1	3.79	16	110	4	1.4
paraxanthine	611-59-6	-0.39	15	290	12	1.7
Hormones and estrogenic activity						
17β-estradiol (E2)	50-28-2	3.94	6	0.079	0	--
estriol (E3)	50-27-1	2.81	20	0.37	15	n.d.
estrone (E1)	53-16-7	3.43	21	0.065	15	n.d.
E-SCREEN estrogenicity			6	0.050	6	0.0038
YES estrogenicity			5	0.096	0	--

Personal care product and consumer product chemicals						
bisphenol A	80-05-7	3.64	19	13	5	0.53
DEET	134-62-3	2.26	16	9	8	0.6
salicylic acid	69-72-7	2.24	15	210	3	3.0
triclosan	3380-34-5	4.66	32	57	11	n.d.
Organophosphate flame retardants						
tris(2-butoxyethyl) phosphate (TBEP)	78-51-3	3.00	13	16	5	1
tributyl phosphate (TBP)	126-73-8	3.82	13	16	5	0.2
tris(2-chloroethyl) phosphate (TCEP)	115-96-8	1.63	22	1.9	8	1.4
tris(chloropropyl) phosphate (TCPP)	13674-84-5	2.89	6	n.d.	0	--
tris(1,3-dichloro-2-propyl) phosphate (TDCPP)	13674-87-8	3.65	22	0.70	8	0.3
Alkylphenols (detergent metabolites)						
nonylphenol	84852-15-3	5.77-5.99	27	1028	10	9.7
NP1EO	104-35-8	5.58	3	7135	2	0.03
NP2EO	26027-38-3	4.48	4	5496	6	11
nonylphenol ethoxylates (longer chain)	various	various	4	9743	1	0.8
NP1EC	3115-49-9	5.80	2	63	1	4.2
nonylphenol ethoxy carboxylates (longer chain)	various	various	6	91	1	0.5
octylphenol	various	5.28-5.50	26	2	10	n.d.
OP1EO	2315-67-5	4.97	13	3	4	2
OP2EO	2315-61-9	NA	13	1	4	n.d.

APPENDIX 2: LIST OF WASTEWATER TREATMENT PLANT ARTICLES

	number of treatment plants included in compilation	acetaminophen	caffeine	carbamazepine	DEET	nonylphenol	sulfamethoxazole	TCEP	triclosan	trimethoprim
Andresen et al. 2004	1							✓		
Batt et al. 2007	1						✓			✓
Bendz et al. 2005	1									✓
Bisceglia et al. 2010	1	✓			✓					
Clara et al. 2005b	3			✓		✓	✓			
Clara et al. 2005a	5			✓						
Foster 2007	1	✓			✓			✓		
Gomez et al. 2007	1	✓	✓							
Jackson and Sutton 2008	3							✓		
Leusch et al. 2006	7					✓				
Meyer and Bester 2004	2							✓		
Nakada et al. 2006	5			✓	✓	✓			✓	
Nakada et al. 2007	1				✓	✓	✓			✓
Rodil et al. 2012	2				✓			✓		
Santos et al. 2007	4		✓	✓						
Santos et al. 2009	4		✓	✓						
Tan et al. 2007	1					✓				
Vogelsang et al. 2006	1					✓				
Watkinson et al. 2009	5									✓
Xu et al. 2007	2						✓			
Yu and Chu 2009	2		✓						✓	
Yu et al. 2006	1	✓							✓	

APPENDIX 3: MEDIA COVERAGE AND EDITORIALS IN LOCAL NEWSPAPERS AND SUBMISSIONS TO SCIENTIFIC JOURNALS

Editorials by Silent Spring Institute researchers

- “Water concerns go beyond nitrates.” Laurel Schaider. *Cape Cod Times.* November 7, 2012.

Editorials by Cape Cod stakeholders

- “A clean water dividend.” Tom Cambareri and Mark Robinson. *Cape Cod Times.* December 11, 2012.

Editorials by Cape Cod Times

- “Study links flame retardants to health problems.” *Cape Cod Times*. December 13, 2012.

News coverage of Silent Spring Institute water research

- “Scientists warn of wastewater contaminants.” *Cape Cod Times*. October 5, 2012.
- “Silent Spring Institute researchers share data on groundwater, household contaminants.” *Cape Cod Today*. October 7, 2012.
- “State grants to fund water-quality projects.” *Cape Cod Times*. June 18, 2013.

Scientific publications

- Schaider LA, Rudel RA, Ackerman JM, Dunagan SC and JG Brody. Pharmaceuticals, Perfluorosurfactants, and Other Organic Wastewater Compounds in Public Drinking Water Wells in a Shallow Sand and Gravel Aquifer. Accepted to *Science of the Total Environment.*

APPENDIX 4: 2012-2013 PRESENTATIONS

Cape Cod

- Barnstable Senior Center, Barnstable, MA, October 5, 2012
- Barnstable Town Hall presentation, Barnstable, MA, October 5, 2012 (slides attached)
- Sustainable Cape Cod Conference, Barnstable, MA, October 22, 2012
- Indian Ponds Association, Annual Meeting, Barnstable, MA, July 14, 2013

Regional

- Maine Water Conference, Augusta, ME, March 19, 2013

National

- Workshop to Broaden the National Dialogue on Contaminants of Emerging Concern and Public Health. Washington, DC. July 17-18, 2013.

CAPE COD TIMES

Water concerns go beyond nitrates

By LAUREL SCHAIDER
November 07, 2012 2:00 AM

A recent environmental summit organized by the Association to Preserve Cape Cod concluded that nutrient pollution is the most important environmental issue on Cape Cod. The problems caused by nutrients in Cape groundwater are apparent. Nutrients, especially nitrate, are causing excessive growth of algae in coastal waters and ponds, choking out plants and animals, and diminishing fish habitats. Household wastewater, primarily from septic systems, is the largest source of nitrate into Cape groundwater.

However, nutrients are not the only contaminants leaching from household wastewater into the Cape environment. Wastewater contains everything that goes down our drains and toilets. It contains chemicals in personal care products, such as detergents and shampoos, and chemicals added to make household products flame resistant, fresh smelling and germ free.

In addition, wastewater contains chemicals that our bodies excrete, including hormones, produced naturally and found in birth control and hormone replacement therapies, and other pharmaceuticals, many of which pass through our bodies without being entirely absorbed. Some of these "emerging contaminants" can act as endocrine disruptors, which mimic the behavior of estrogens and other hormones.

My own research at Silent Spring Institute and earlier studies show these contaminants are widespread in Cape drinking water, groundwater and ponds. Our recent studies have found pharmaceuticals, consumer product chemicals, including perfluorinated chemicals used in nonstick and stain-resistant products, and other emerging contaminants in 75 percent of the public drinking water wells and 85 percent of the private wells that we tested throughout the Cape.

Public wells and ponds in more heavily populated areas had higher levels of emerging contaminants. So did drinking water wells with higher levels of nitrate, even at levels well below the federal drinking water standard for nitrate. Nitrate is regulated in drinking water because high levels can be harmful to infants, but it is also an important indicator that the water may contain emerging contaminants, too.

These contaminants need to be part of the planning to protect the Cape's environment along with nutrient reductions. The presence of emerging contaminants alone does not mean they are harmful, and the levels of pharmaceuticals typically found in Cape groundwater are much smaller than the doses used in medicines.

However, while we are exposed to complex mixtures, scientists usually study just one chemical at a time, and we do not yet understand how low levels of many different compounds may interact with one another, especially during sensitive stages of development before birth and in children. Endocrine disruptors can show effects at lower doses that are not apparent at higher doses.

Although emerging contaminants are not currently regulated in drinking water, the Environmental Protection Agency is considering some of them for future regulation.

As we work to fill gaps in our understanding of the health effects of emerging contaminants, it is wise to find ways to minimize exposures. While areas that are sources of nutrients into impaired coastal systems are currently the priority for sewers, concerns about emerging contaminants suggest that areas close to drinking water supplies should also be priorities.

In addition, while centralized treatment plants generally do a better job of removing emerging contaminants than septic systems, all wastewater discharges will contain emerging contaminants. Some Cape residents favor alternatives to sewers such as eco-toilets and cluster systems; less is known about how these alternatives will address emerging contaminants. Evaluating inputs of emerging contaminants to Cape groundwater under current and proposed treatment scenarios is one of the goals of Silent Spring Institute's next Cape study.

All Cape residents rely on groundwater as a source of drinking water, and all Cape wastewater is discharged into that same groundwater. Minimizing wastewater chemicals in drinking water means prioritizing zones of contribution for public and private wells for sewers or advanced on-site treatment and avoiding new wastewater discharges in these zones.

Protecting the quality of Cape drinking water will require a concerted effort to minimize the impact of wastewater contaminants. What is at stake involves far more than just nitrate, and the solutions may have implications for the health of all Cape residents.

Laurel Schaider is a research scientist at Silent Spring Institute in Newton and leads the institute's studies of water quality on Cape Cod.

CAPE COD TIMES

A clean water dividend

By **TOM CAMBARERI**
December 11, 2012 2:00 AM

and MARK ROBINSON

Dr. Laurel Schaider of the Silent Spring Institute recently commented in this space (Nov. 7) on the issue of Compounds of Emerging Concern (CEC), nitrates, and how protection and restoration of our drinking water needs to be integrated into the Cape's future plans for wastewater management.

Dr. Schaider's point is well taken since it seems that the Cape's public concerns for wastewater management are driven by the issue of nitrogen loading of our coastal waters.

Perhaps our recent turn of attention to coastal water quality reflects our relative success in protecting drinking water quality. About 50 years ago, Cape Codders began to recognize local, regional and state action was needed to protect our aquifer. We have identified and refined wellhead protection areas; ceased harmful activities, like landfills, septage lagoons, and leaking underground storage tanks; developed groundwater clean-up technology and industry; secured the cleanup of the Massachusetts Military Reservation; established land use protection strategies; and permitted sustainable supplies from new wells.

All citizens contribute to this effort when they vote to purchase open space for water quality protection at town meetings and water districts, when they donate land and dollars to local land trusts, and when they approved the Cape Cod Land Bank, Community Preservation Act and bylaws to protect wetlands and wellfields.

There are more than 160 gravel-packed wells and hundreds of private wells from which we pump nearly 10 billion gallons of clean and virtually untreated groundwater each year. The state and federal standards require less than 10 parts per million (ppm) of nitrates in drinking water; the county planning goal is less than 5 ppm of nitrates.

Owing to our protective strategies, 40 percent of the Cape's drinking water supply is obtained from large protected areas with nitrate concentrations less than one-half a part per million. Another 20 percent is produced from protected areas with nitrates less than 1 ppm. Only a handful of public wells, many which were installed in the 1950s-60s in the midst of high-density development, approach the county standard of 5 ppm.

Reports about detections of CECs at the nanogram level (six orders of magnitude less than a part per million) across the nation's water supplies have raised the bar for concern about these unregulated compounds. We are grateful that Silent Spring, working with our water districts, has provided us with a better understanding of the occurrence of these unregulated compounds in the Cape's public water supplies.

Silent Spring reports the number of detections of CECs is higher in those less-protected wells than the majority wells that are well protected, confirming what our intuition tells us. Saving open space and adopting strong, scientifically based protection strategies has given Cape Cod a clean drinking water dividend.

While the scientific community works to resolve the health threats posed by these trace compounds, we here on the Cape should proceed with the more in-depth studies that Silent Spring advocates, including continued evaluation of drinking water quality; identification of problematic areas; develop clear strategies for remediation; and optimize water supply sources, including the potential of minimizing or replacing impacted wells (private and public) with better protected sources. With this approach we can focus our capital on those drinking water areas that truly require it and institute sustainable management solutions where we can.

Work to remove nitrogen from Cape Cod's coastal watersheds to restore marine water will result in significant volumes of wastewater being treated. Finding the proper locations to discharge treated effluent is a critical wastewater management issue. But, additional treatment of wastewater, beyond nitrogen removal, to remove CECs by reverse osmosis is significantly more expensive and typically reserved for water-deficit areas, like the

Caribbean islands. That is a cost premium we can avoid by wisely locating potential treated effluent discharges outside of our critical wellhead protection areas and maintaining the advantage of our clean water dividend. We earned it!

Tom Cambareri is water resources program manager of the Cape Cod Commission and Mark Robinson is executive director of the Compact of Cape Cod Conservation Trusts Inc.

CAPE COD TIMES

Emerging concerns

Study links flame retardants to health problems

December 13, 2012 2:00 AM

A recent study in California found that homes contained levels of at least one flame retardant that exceeded a federal health guideline.

Published in the journal "Environmental Science & Technology" on Nov. 28, the study was led by scientists at Silent Spring Institute of Newton and Cape Cod. Forty-four flame retardant chemicals were detected and 36 were found in at least 50 percent of the samples, sometimes at levels of health concern. The flame retardants, found in house dust, are contained in furniture, textiles, electronics and other products.

According to Silent Spring, the chemicals used in flame retardants contain hormone disruptors and carcinogens.

How does this latest study affect Cape Cod? First, the flame retardants are pervasive and exist in most American homes. Second, the chemicals contained within flame retardants represent Compounds of Emerging Concern, something Cape water officials need to consider as they develop wastewater management strategies.

Currently, local wastewater management planners are focusing on nitrates, which seep from our septic systems and eventually pollute our coastal embayments.

Silent Spring officials are trying to convince Barnstable County health officials, the Cape Cod Water Protection Collaborative and the Cape Cod Commission to consider Compounds of Emerging Concern in future wastewater management decisions.

However, that's an expensive proposition. In a My View published earlier this week, Tom Cambareri, water resources program manager at the Cape Cod Commission, and Mark Robinson, executive director of the Compact of Cape Cod Conservation Trusts Inc., said detections of

CECs at the nanogram level (six orders of magnitude less than a part per million) across the nation's water supplies have raised the bar

for concern about these unregulated

compounds.

"We are grateful that Silent Spring ... has provided us with a better understanding of the occurrence of these unregulated compounds in the Cape's public water supplies," they wrote. "We here on the Cape should proceed with more in-depth studies that Silent Spring advocates, including continued evaluation of drinking water quality; identification of problematic areas; develop clear strategies for remediation... . With this approach we can focus our capital on those drinking water areas that truly require it."

At the same time, they wrote, additional treatment of wastewater, beyond nitrogen removal, to remove CECs is typically reserved for water-deficit areas, such as the Caribbean islands.

As a result, removing CECs may be necessary in limited areas on Cape Cod, but it may not be necessary to include CECs across the entire Cape.

The other broader issue that must be addressed related to this latest Silent Spring study is the need for improved federal rules on flame retardants.

"The potential harm from fire retardant chemicals used in furniture is very concerning," said Dr. Vytenis Babrauskas, an independent fire safety scientist. "My research found that the California fire standard provides no meaningful protection against the hazard it addresses — furniture ignited by small flames. In view of the toxicity of substances put into furniture foam to meet the California standard, the rule does more harm than good."

At the national level, Congress is considering the Safe Chemicals Act to make sure chemicals in consumer products are safety tested before they go into use.

After all, scientists are concerned about the impact of these chemicals, especially on pregnant women and children.

Silent Spring's research adds to the overall

scientific body of knowledge, and its study

conclusions represent small but valuable

steps.

CAPE COD TIMES

Scientists warn of wastewater contaminants

By **Cynthia Mccormick**
cmccormick@capecodonline.com
October 05, 2012 2:00 AM

HYANNIS — As local officials deal with wastewater issues, they should pay attention to the chemicals Cape Codders are flushing down the drain, researchers from the Silent Spring Institute said during an update Thursday.

Cape residents need to protect themselves from contaminants in medicine and household products that are ending up in local wells via wastewater, they said in a presentation at Barnstable Town Hall.

These chemicals are known as "emerging contaminants," because the ability to detect them in the environment only has been available in recent years.

Chemicals making their way into the local water supply include pharmaceutical products, plasticizers, hormones, herbicides, flame retardants and perfluorinated chemicals from nonstick and stain-resistant products.

Many of the chemicals are considered hormone disruptors that act like estrogen, which has caused breast cancer cells to grow in a laboratory setting.

"Everyone on the Cape relies on groundwater as a source of drinking water," said Silent Spring Institute scientist Laurel Schaider, who will be a panelist at a wastewater conference sponsored by the Cape Cod Commission Oct. 22 and 23 in Hyannis.

Although no federal standards have been developed yet to regulate emerging contaminants, Schaider said they are "on the radar" of the U.S. Environmental Protection Agency.

Schaider said the Cape's drinking water is especially vulnerable to contamination because the area's sandy, porous soil allows wastewater to move more quickly into the water supply.

"It just makes sense to try to keep our drinking water separate from wastewater," Schaider said.

The Newton-based Silent Spring Institute was established to explore possible environmental links to the Cape's high rate of breast cancer.

In recent years the institute has released studies that show the presence of dozens of emerging contaminants in public and private wells on the Cape.

Of the 20 private wells tested in February 2011, at least one emerging contaminant was found in 85 percent of them, Schaider said.

"Where you've got nitrates, you've also got these contaminants," she said.

"We don't know the health implications yet," she said.

Jean Crocker of Cotuit, who attended the afternoon session at town hall, said years ago the Cape's small population and lack of industry meant the drinking water was considered especially pure.

But the Cape, considered a sole-source aquifer, is at special risk of water contamination, she said.

"We are very unique. We are only sand. We don't have that sub-base of granite like the rest of the U.S.," she said.

Silent Spring Institute researchers share data on groundwater, household contaminants

ARTICLE | NEWS | OCTOBER 7, 2012 - 10:35PM

by Matilda Brown

Two researchers from the Silent Spring Institute came to Barnstable Town Hall to speak about research that they have done on the Cape in regards to chemical contaminants in the groundwater, as well as household exposures.

The Silent Spring Institute works to identify links between women's health and the environment, particularly breast cancer, according to researcher Dr. Laurel Schaider.

Schaider said that her studies focus on finding out what chemicals are problematic, how people are being exposed to them, and how to then regulate those chemicals. Schaider is interested in several types of chemicals, including those that act as mammary carcinogens and damage DNA, endocrine disruptors that may make tumors grow (like BPA), and developmental toxicants that increase susceptibility (DES).

Schaider said that most of the contaminants get into the water supply from the wastewater. Wastewater management is currently an issue on the Cape, with various town's and agencies trying to find solutions.

Currently, most of the chemicals that Schaider studies are not regulated in drinking water, and very few of them have health-based guidelines. The guidelines are suggestions and are not often enforced.

The chemicals in the wastewater come from sources such as pharmaceuticals, personal care products, household products, and our own bodies (hormones). The way the wastewater contaminates the aquifer is through septic systems. At least 80% of the homes on the Cape have a septic system. Schaider said that the Cape's groundwater is uniquely vulnerable because the aquifer is unconfined (there is no bedrock, only sand and gravel).

Some of Schaider's work has consisted of testing ponds on the Cape for chemicals. She tested several ponds in areas with higher population densities and ponds in areas with lower population densities. She found that the ponds in areas that had more residential development had correspondingly higher levels of chemicals - especially hormones and pharmaceuticals - something Schaider said could be partly attributed to the presence of more septic systems.

Schaider's drinking water study involved nine public water supply districts. The wells were tested for pharmaceuticals, hormones, alkylphenols, and chemicals from household and consumer products.

Overall, researchers tested for 92 chemicals. Eighteen chemicals were found with levels in the parts per trillion. One part per trillion is equal to one nanogram per liter. Most drinking water guidelines for chemicals are given in micrograms per liter, which is a larger amount than nanograms. However, Schaider cautioned that some of these chemicals may be found to be of concern even at the parts per trillion level.

For two of the pharmaceuticals tested for, the levels matched or exceeded the highest levels found in testing throughout the United States.

Factors that influence the amount of chemicals in the wells are the extent of residential development in well recharge areas, as well as higher levels of nitrate and boron which are associated with higher levels of other chemicals.

According to CapeCodGroundWater.org, "Nitrate, is often used as an indicator of drinking water quality. A maximum contaminant limit (MCL) of 10 ppm [parts per million] of nitrate as nitrogen for drinking water supplies has been established by the US EPA and adopted by MA state regulation."

Schaider's study also looked at private wells which serve 20% of the Cape's residents, particularly in towns on the Lower Cape, some of which rely almost exclusively on private wells.

In the private wells, Schaider said that 85% had at least one chemical present with acesulfame (an artificial sweetener) being one of the most common chemicals found. Schaider said that acesulfame is not designed to break-down (which is why it is touted as a lower calorie option for dieters) and that is why it tends to end up in the wells.

Schaider said that pharmaceuticals were found in 2/3 of the private wells studied.

The four most common chemicals in public and private wells were sulfamethoxazole (an antibiotic), carbamazepine (an anti-convulsant and mood stabilizer used to treat epilepsy and bipolar disorder), PFOS (Perfluorooctane sulfonate), and TEP (triethyl phosphate, a flame retardant).

Wells with higher nitrate levels were found to have more contaminants and higher pharmaceutical concentrations.

Schaider said that while the chemicals may be of concern on their own, she is also interested in the effects of the chemicals when mixed.

Schaider said that people should consider filtering their tap water if their well has elevated nitrate, saying that for elevated nitrate, solid carbon block filters can be effective. According to Schaider, the results of her study are not meant to encourage people to buy bottled water, saying "public water supplies are better treated and protected than bottled water and private wells."

A way to prevent chemicals from getting into the wastewater is by maintaining septic systems and reducing the use of household products with chemicals of concern, according to Schaider. She said another proactive approach to getting contaminants out of the water supply is to support local efforts to clean up the groundwater supply.

Schaider said that while sewering and other alternatives are being debated on the Cape in terms of wastewater management, she is interested in evaluating alternatives, like composting toilets, if funding becomes available.

However, Schaider cautioned that wastewater needs to be kept out of the drinking water. If sewering is near the water supply, where the effluent goes needs to be monitored. Schaider said that on-site treatment of wastewater also needs to be advanced.

Land acquisitions near public wells need to be carefully considered and if a private well becomes affected by contaminants, there should be a plan for offering water from a public well as an alternative, according to Schaider.

Dr. Robin Dodson worked on household exposure studies. She said that two have been performed, one on the Cape and one in Northern California. She said, on average, people are exposed to about 20 chemicals in their homes and that DDT was found in 2/3 of the homes in her study. Overall, Dodson said, 67 Endocrine Disrupting Chemicals (EDCs) and 27 pesticides were found.

Dodson mentioned that phthalates were found in 100% of the homes in her study. Phthalates are still being studied to determine their potential risks to health. She said that parabens and alkylphenols were also abundant in the homes in her study.

Some of the most common EDCs found by Dodson were in fact the parabens (used widely, especially in cosmetic products and pharmaceuticals), UV filters, and triclosan (an ingredient in most hand soaps, as well as some toothpastes and other products).

Dodson performed a comparison study between conventional and alternative household products. There were chemicals of concern present in all the conventional products, but 11 out of the 43 alternatives studied did not have any chemicals of concern present. Additionally, most of the chemicals in the alternatives were found at lower levels than those in the conventional products.

The chemicals found in the highest concentrations throughout the study were UV filters, DEHP (Bis phthalate [currently being phased out of production in the EU]), fragrance, DEA (diethanolamine [a possible carcinogen]), and glycol ethers.

Dodson's study on endocrine disruptors and asthma-associated chemicals can be found at here.

A problem with figuring out what chemicals are present in what products is that many of the products are not required to label all their chemicals, said Dodson. Generally speaking though, most UV filters, parabens, and anti-microbials are labeled. Dodson says that better labeling is needed.

Dodson said that she has conducted intervention studies to see what people can do to effectively lower the presence of these chemicals in their lives. Particularly effective, said Dodson, are organic and vegetarian diets, as well as reduced use of food packaging.

Dodson said she also recommends limiting use of sunscreen and using shade, hats, and tightly woven clothing instead to protect against UV exposure. Recently, there has been some talk about the potential health risks posed by some of the chemicals in sunscreen.

Dodson said that in regards to triclosan, it has now been found that washing with regular soap and warm water is just as effective as using anti-microbial products (this is acknowledged by the CDC on their website). Triclosan, an EDC, has been associated with thyroid hormone disruption.

Another way to reduce exposure, said Dodson, is to go back to "cleaning like your grandmother did", with water, baking soda, and vinegar. Dodson said using fewer products in general is another proactive approach people can take to reducing their chemical exposure, as well as using products with plant based ingredients.

Lastly, Dodson said especially important to avoid are cyclosiloxanes (particularly cyclomethicone), which are found in numerous personal care products, because they can imitate estrogen.

Dodson also recommended avoiding products with lavender and tea tree oil (especially if you are a boy) because there was a study published by the *New England Journal of Medicine* that indicated that lavender and tea tree oil could cause breast budding in boys because they may mimic estrogen. However, Dodson acknowledged there need to be more studies done before this can definitively asserted.

Mati Brown holds a Journalism degree from the University of Massachusetts – Amherst. She has written for several publications, including the Berlin Reporter, EDGE publications, and the Falmouth and Mashpee Bulletins. A current resident of Brewster, she is glad to be writing about the area she grew up in.

CAPE COD TIMES

State grants to fund water-quality projects

By **Sean F. Driscoll**
sdriscoll@capecodonline.com
June 18, 2013 2:00 AM

HYANNIS — While many eyes focus on the land when discussing changes to ocean levels, the Association to Preserve Cape Cod is casting its collective gaze underground with the help of a state grant.

The association is launching a three-year effort to examine the effect of rising seas on the Cape's freshwater aquifers. Monday, it received an $80,000 grant from the Massachusetts Environmental Trust to aid in its work.

Six Cape and Islands-affiliated programs or towns received a grant from the trust, with Energy and Environmental Affairs Secretary Rick Sullivan announcing local awards at a news conference held at the John F. Kennedy Memorial on Ocean Street. In all, almost $600,000 was awarded to 12 organizations across the state from the environmental trust, which has provided $19 million to organizations since it was founded in 1988. The trust uses money raised by the sale of three environmentally themed license plates to fund projects.

Ed DeWitt, executive director of the Association to Preserve Cape Cod, said the study, which will cost $175,000, will provide data on areas on the Cape that could be susceptible to groundwater problems when sea levels rise. Some potential issues include rising pond levels, encroachment of septic system leach fields on water supplies and damage to roads and buildings.

"The good news is we have time," he said. But the bad news, he said, is this is one of the issues that's "out of sight" when rising sea levels are discussed.

Other local towns and organizations receiving grants were:

- Friends of Herring River, Wellfleet: $50,000 for preliminary engineering design and construction cost estimate for replacement of the Chequesset Neck Road dike and culvert, both part of the 800-acre estuary restoration.
- Provincetown Center for Coastal Studies, Provincetown: $46,500 to continue and expand a water-quality testing and monitoring program for Nantucket Sound, including testing for pharmaceutical compounds.
- Silent Spring Institute, Newton: $50,000 to estimate levels of new contaminants, including hormones and pharmaceuticals and chemicals from consumer products, to the Cape Cod aquifer and evaluate how they'd change under proposed alternative wastewater scenarios.
- Town of Falmouth: $55,000 for engineering and plans to remove Lower Bog Dam, restore a portion of the Coonamessett River and restore 17 nearby acres.
- Town of Oak Bluffs: $50,000 for engineering and permitting for an improved opening between Farm Pond and Nantucket Sound. The larger opening will improve water quality and improve shellfish beds.

APPENDIX 4: 2012-2013 PRESENTATIONS

Cape Cod

- Barnstable Senior Center, Barnstable, MA, October 5, 2012
- Barnstable Town Hall presentation, Barnstable, MA, October 5, 2012 (slides attached)
- Sustainable Cape Cod Conference, Barnstable, MA, October 22, 2012
- Indian Ponds Association, Annual Meeting, Barnstable, MA, July 14, 2013

Regional

- Maine Water Conference, Augusta, ME, March 19, 2013

National

- Workshop to Broaden the National Dialogue on Contaminants of Emerging Concern and Public Health. Washington, DC. July 17-18, 2013.

SILENT SPRING INSTITUTE

RESEARCHING THE ENVIRONMENT AND WOMEN'S HEALTH

Silent Spring Institute Research Update

Laurel Schaider, Ph.D.

Robin Dodson, Sc.D.

SILENT SPRING INSTITUTE

RESEARCHING THE ENVIRONMENT AND WOMEN'S HEALTH

SILENT SPRING INSTITUTE is a non-profit scientific research organization dedicated to identifying the links between the **environment and women's health**, especially breast cancer.

We are a groundbreaking collaboration of scientists, physicians, health advocates, and community activists, and a leading edge research institution using multi-disciplinary, state-of-the-art approaches.

"A lab of our own"

www.silentspring.org

Prevention Evidence

Biological mechanism + **Human exposure**

Basis for action

Education
Regulation
Reformulation

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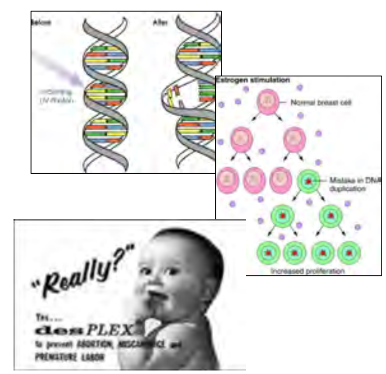
Chemicals of Interest

- Mammary carcinogens damage DNA
- Endocrine disruptors may make tumors grow
- Developmental toxicants increase susceptibility



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Brody & Rudel, 2003, EHP

Today's Update

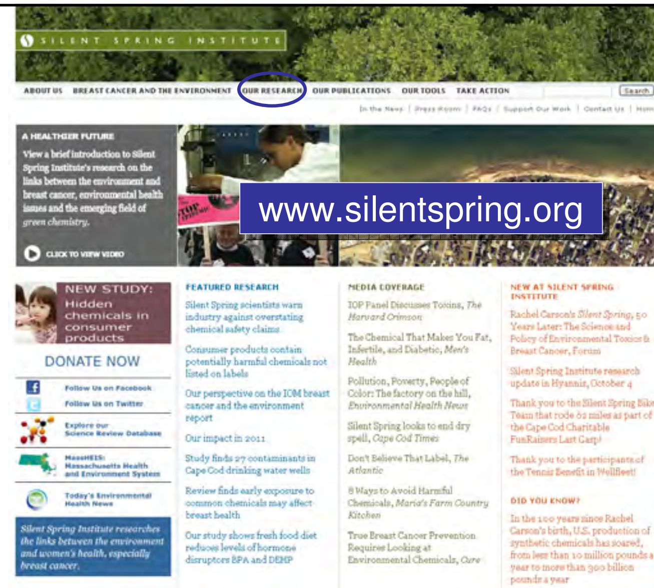
Contaminants of emerging concern in Cape drinking water and groundwater

Dr. Laurel Schaider

Hormone disruptors and asthma-associated chemicals in household products

Dr. Robin Dodson

www.silentspring.org



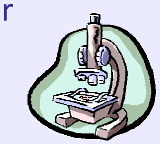
Beyond nitrate: Emerging contaminants and water quality of Cape Cod

Pharmaceuticals and other contaminants of emerging concern in Cape Cod drinking water, groundwater and ponds

Laurel Schaider, Ph.D.
Research Scientist
Silent Spring Institute
October 4, 2012

Emerging contaminants: A new set of concerns

- Growing awareness of their presence in the environment, often from wastewater
- New analytical techniques can measure low levels in the environment
- Health implications not yet known, most not regulated in drinking water



Emerging contaminants: What are we talking about?

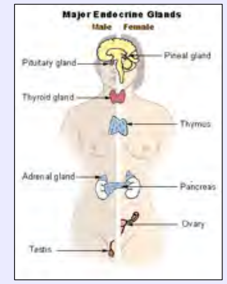
- Pharmaceuticals
- Personal care products
- Chemicals in household products
  - Flame retardants
  - Non-stick and stain resistant chemicals
  - Detergent chemicals
- Chemicals produced by our bodies
  - Hormones




www.silent

Endocrine disruptors

- Classified by their mode of action
- Interfere with natural hormones
- Examples:
  - natural and synthetic estrogens
  - bisphenol A
  - organochlorine pesticides
  - PCBs
  - PBDEs (flame retardants)
  - alkylphenol ethyoxylates (from detergents)



http://www.web-books.com/eLibrary/Medicine/Physiology/Endocrine/Endocrine.htm

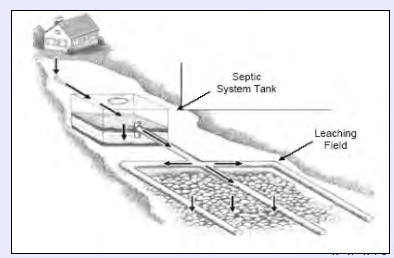
www.silentspring.org

How do emerging contaminants get into the environment?

http://pubs.acs.org/cen/coverstory/86/8608cover.html

Why is Cape groundwater vulnerable?

- Unconfined aquifer with sand and gravel
- Soils that are acidic with low organic carbon
- 85% of Cape residents have septic systems



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Silent Spring Institute
Cape water research questions

- What are the levels of endocrine disruptors and other emerging contaminants in Cape drinking water and groundwater?
- What happens as these chemicals move through the ground and treatment systems?
- How should emerging contaminants be considered in future planning of wastewater treatment and drinking water protection?

Previous studies

Silent Spring Institute

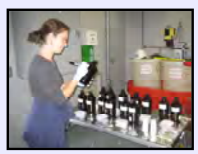
- Pharmaceuticals and endocrine disruptors in groundwater and septage [a,b]
  - Chemicals can persist in low oxygen portions of aquifer
- Hormones and pharmaceuticals in Cape Cod ponds [c]
  - Higher levels, more frequent detections in more developed areas

U.S. Geological Survey

- Emerging contaminants in drinking water [d]
  - Pharmaceuticals, flame retardants in public and private wells

[a]Rudel et al. 1998; [b]Swartz et al. 2006; [c]Standley et al. 2008; [d]Zimmerman 2005

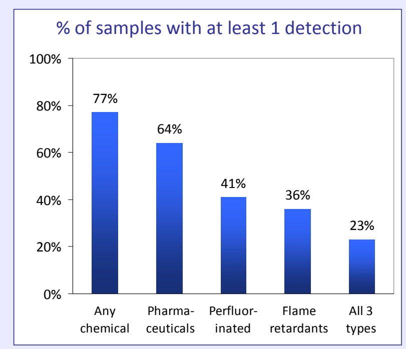
Cape Cod public drinking water study



- 9 public supply districts
- 20 groundwater wells tested for: pharmaceuticals, hormones, alkylphenols, and chemicals from household and consumer products
- Samples collected in October 2009
- Water suppliers wanted to learn more, despite lack of regulations and understanding of health effects

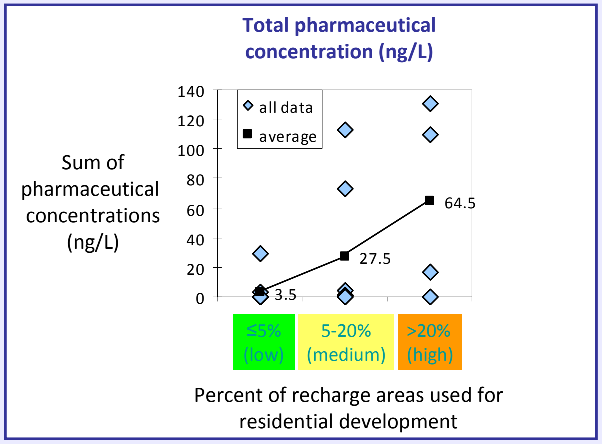
What did we find?

- Tested for **92** chemicals
- **18** chemicals detected at parts per trillion levels
  - 9 pharmaceuticals
  - 1 insect repellent
  - 2 perfluorinated chemicals
  - 5 flame retardants
  - 1 alkylphenol

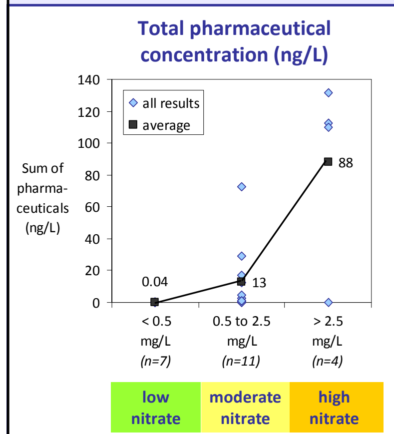


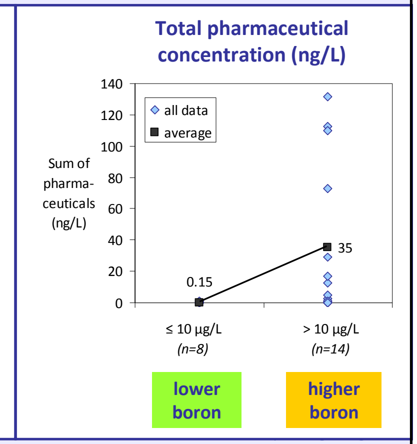
- 15 of 20 wells and both distribution systems contained at least one chemical
- For 2 pharmaceuticals, our highest levels matched or exceeded the highest levels in other U.S. studies

Wells with more residential development had more emerging contaminants…



…so did wells with higher nitrate and boron

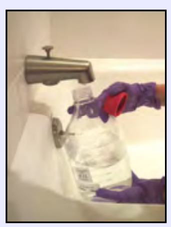




Cape Cod private drinking water study

- 20 private wells tested for similar range of chemicals
- Samples collected in February 2011
- Included a range of locations and likely impacts, emphasized moderately and highly impacted wells

Town	Wells tested
Barnstable	3
Brewster	2
Eastham	5
Falmouth	1
Sandwich	1
Truro	3
Wellfleet	5



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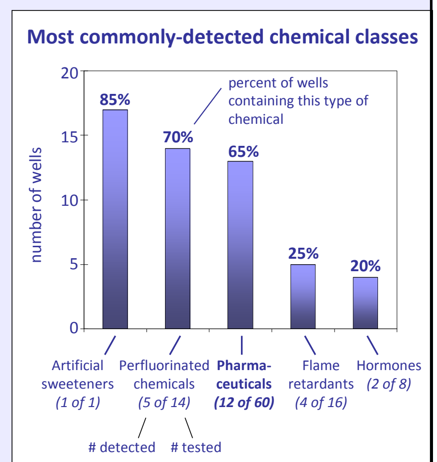
Overall findings

- 85% of the wells had at least one emerging contaminant
- 27 of 121 emerging contaminants were found at least once
- Zero to 13 chemicals in each well



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Most commonly-found chemicals

units: nanograms per liter (ng/L) = parts per trillion (ppt)

Chemical	Category/uses	No. of wells (%)	Maximum concentration
Acesulfame	Artificial sweetener	17 (85%)	5300 ng/L
PFHxS	Perfluorinated chemicals Present in non-stick and stain-resistant coatings for textiles, paper, and other household products; fire-fighting foams and some industrial processes	11 (55%)	41 ng/L
PFBS		11 (55%)	23 ng/L
PFOS		11 (55%)	7 ng/L
PFHxA		10 (50%)	2 ng/L
Sulfamethoxazole	Antibiotic	9 (45%)	60 ng/L

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Comparisons to public wells

- Results were generally similar for chemicals tested in both
- 4 most common chemicals in public wells were also found in private wells:
  - sulfamethoxazole
  - carbamazepine
  - PFOS
  - TEP (flame retardant)
- Some chemicals only found in public or private wells

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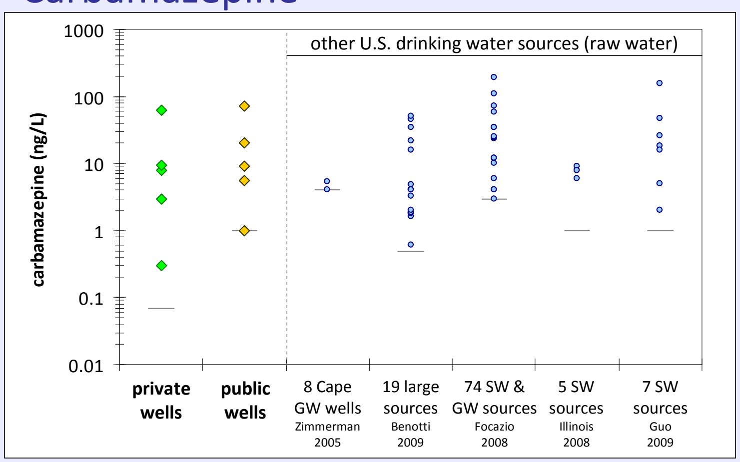
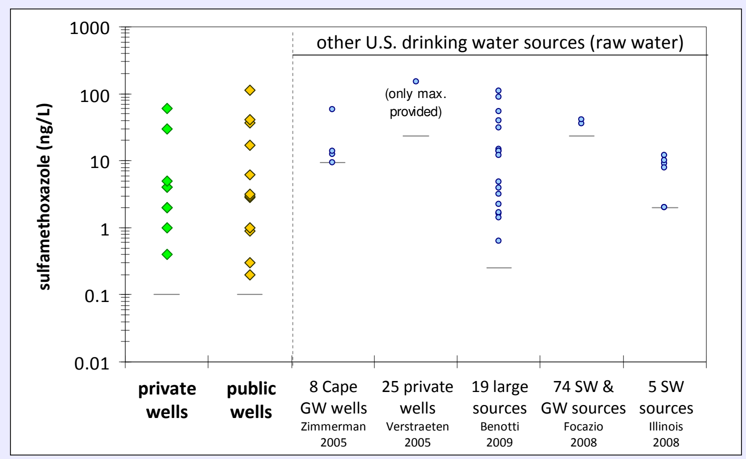
Carbamazepine



GW = groundwater, SW = surface water, — = MRL, DL, or lowest value reported

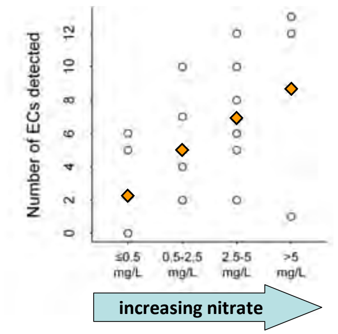
Sulfamethoxazole



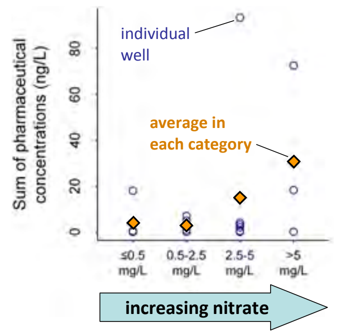
GW = groundwater, SW = surface water, — = MRL, DL, or lowest value reported

Wells with higher nitrate levels had…

… more emerging contaminants



… higher pharmaceutical concentrations



Comparisons to guidelines

- No regulated drinking water standards
- Health-based guideline values – 6 chemicals
  - PFOA, PFOS, PFBS, DEET, carbamazepine, TCEP
  - PFOS and PFOA: 2 public well samples were half of lowest guideline
  - Other chemicals were well below guideline values
- Guideline values not available for most emerging contaminants

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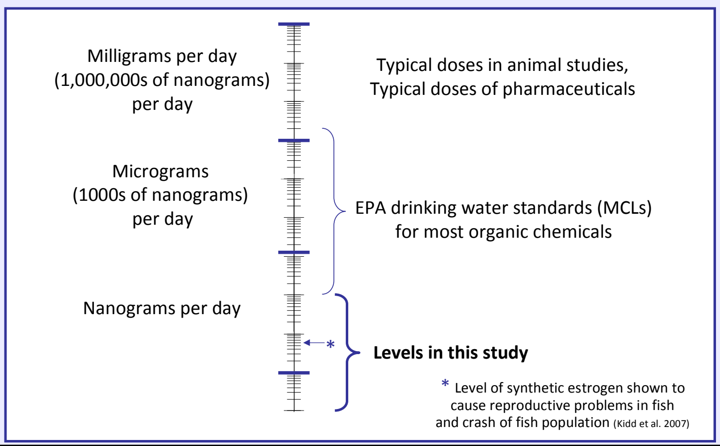
What is a part per trillion?

1 part per trillion = 1 nanogram per liter
Expressed as approximate daily intake



What is a part per trillion?

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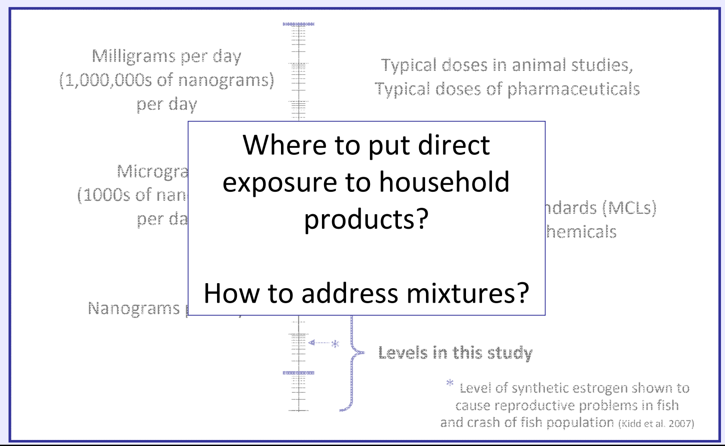

What can I do?

- Consider filtering tap water if wells in your district have elevated levels of nitrate or if you have a private well
  - Solid carbon block filters can be effective
  - Public water supplies are better tested and protected than bottled water or private well water
- Prevent chemicals from getting into wastewater
  - Don't flush unused medications or hazardous materials
  - Reduce use of household products containing harmful chemicals
  - Maintain septic systems
- Support local efforts to protect water quality
  - Prevent discharges in well recharge areas
  - Land acquisition to protect open space

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Emerging contaminants and wastewater planning on the Cape

- Towns grappling with excessive nutrients
- Priority areas: impaired coastal ecosystems
- Sewering and alternatives are being debated
- Where do emerging contaminants fit into this discussion?

Comparing conventional and alternative wastewater treatment approaches

- Evaluate how different approaches and scenarios for treating wastewater will affect inputs of emerging contaminants into Cape groundwater
  - Compare typical levels of emerging contaminants and removal efficiencies in septic systems and centralized treatment plants
  - Measure hormones and pharmaceuticals in composting toilet residuals

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Implications

- Precautionary approach: keep wastewater out of drinking water
  - Sewering near water supplies (but watch where effluent goes)
  - Advanced onsite treatment
  - Land acquisitions near public wells
  - Public water in areas where private wells are impacted
- Emerging contaminants are not regulated...yet
  - Drinking water standards may be developed
  - Towns are making large investments in infrastructure...how can we plan ahead?

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Acknowledgements

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- Mass. Environmental Trust
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- Underwriters Laboratories
- Study volunteers and participating water supply districts

Contact information:
Laurel Schaider, Ph.D.
Research Scientist
schaider@silentspring.org

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Contains water research section

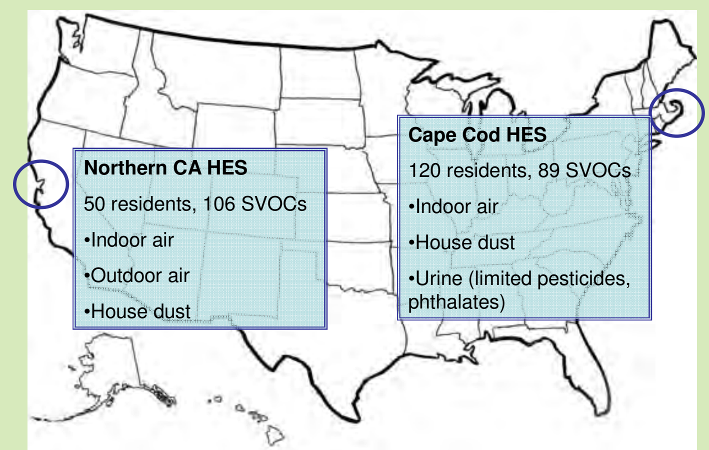
Links to report and other documents

GIS-based tool with health and environmental data

Hormone disruptors and asthma-associated chemicals in household products

Robin Dodson, ScD
Research Scientist
Silent Spring Institute

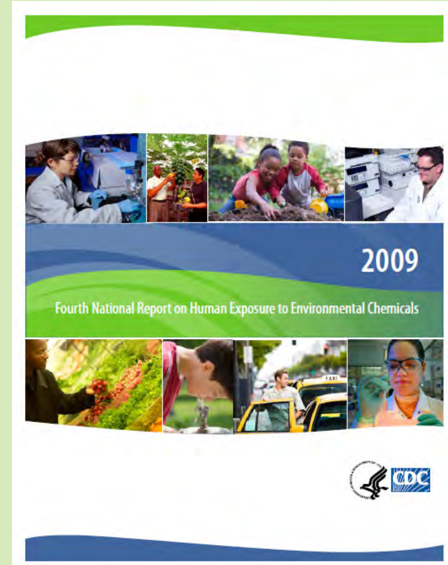
Silent Spring's Household Exposure Study



What are We Exposed To?

- About 20 chemicals per home
- 67 EDCs, 27 pesticides
- DDT 2/3 of homes
- Phthalates - 100% homes
- Parabens, alkylphenols - abundant
- Flame retardants - MA 10 x Europe levels; CA 200 X Europe
- 15 chemicals above guidelines (39 have guidelines)
- 100 of 120 homes above health guidelines

Rudel et al. 2003 and 2010 ES&T



How can I reduce my exposure while science and regulations are being worked out?

What exposure source is priority for control?

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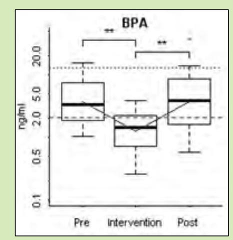
Evidence-based exposure reduction

- Intervention studies
  - Organic diets (Lu et al., 2005 EHP)
  - Reduced food packaging (Rudel et al., 2011 EHP)
  - 5-Day vegetarian diet – temple stay (Ji et al., 2010 Env Res)
- For household products – we first need to ID major sources and substitutes



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50 product types

Dodson et al. 2012

66 endocrine disruptors and asthma-associated chemicals

parabens	UV filters	phthalates	ethanolamines
triclosan	cyclosiloxanes	fragrances	
alkylphenols	BPA	glycol ethers	

Asthma associated

Dodson et al. 2012 EHP

Chemical Class	Use(s) in Products[a]	Potential Health Concerns[b]	Chemicals
parabens	preservative; anti-microbial agent	endocrine disruption (Kang et al. 2002)	methyl paraben ethyl paraben butyl paraben
phthalates	plastic additives; solvents in cosmetics and perfumes; inert ingredient in pesticides	endocrine disruption (Hannas et al. 2011; Hauser et al. 2006; Heindel et al. 1989; Howdeshell et al. 2008; Meeker et al. 2009; Mendiola et al. 2011; Swan et al. 2005). asthma associated (Bornehag et al. 2004; Bornehag and Nanberg 2010)	bis(2-ethylhexyl) adipate bis(2-ethyhexyl) phthalate benzylbutyl phthalate *di-amyl phthalate* di-cyclohexyl phthalate di-isobutyl phthalate di-isononyl phthalate di-n-butylphthalate di-n-hexyl phthalate di-n-octyl phthalate di-n-propyl phthalate diethyl phthalate
bisphenol A	production of polycarbonate plastic and epoxy resins	endocrine disruption (FAO/WHO 2010; NTP-CERHR 2008)	bisphenol A
antimicrobials	anti-microbial agent	endocrine disruption (Chen et al. 2008; Orton et al. 2011; Stoker et al. 2010)	*1,4-dichlorobenzene* *o-phenylphenol* triclosan triclocarban
ethanolamines	solvent in cleaners; emulsifier in creams and lotions	asthma associated (Kamijo et al. 2009; Makela et al. 2011; Piipari et al. 1998; Savonius et al. 1994)	monoethanolamine diethanolamine

Chemical Class	Use(s) in Products[a]	Potential Health Concerns[b]	Chemicals
alkylphenols	surfactant; disinfectant; inert ingredient in pesticides	endocrine disruption (Jie et al. 2010)	4-t-octylphenol octylphenol monoethoxylate octylphenol diethoxylate 4-t-nonylphenol nonylphenol monoethoxylate nonylphenol diethoxylate
fragrances	scent; masking agent	endocrine disruption (Bitsch et al. 2002; Schreurs et al. 2005; Seinen et al. 1999; van der Burg et al. 2008) asthma associated (Kumar et al. 1995)	natural[c] benzyl acetate eugenol hexyl cinnemal limonene linalool methyl eugenol methyl salicylate pinene terpineol synthetic AHTN bucinal diphenyl ether DPMI HHCB isobornyl acetate methyl ionone musk ketone musk xylene phenethyl alcohol

Chemical Class	Use(s) in Products[a]	Potential Health Concerns[b]	Chemicals
glycol others	solvent	asthma associated (Choi et al. 2010)	*2-isopropoxyethanol (R2)* *2-propoxyethanol (R2)* 2-butoxylethanol 2-phenoxylethanol (R2) *2-benzyloxyethanol (R2)* 2,2-methoxyethoxyethanol *2,2-ethyoxyethoxyethanol (R2)* 2,2-butoxyethoxyethanol (R2)
perfluorinated	stain resistance	endocrine disruption (White et al. 2011)	*8:2 FTOH*
cyclosiloxanes	enhance conditioning and spreading	endocrine disruption (Quinn et al. 2007) carcinogenicitiy (Wang et al. 2009)	octamethylcyclotetrasiloxane (D4) (R2) decamethylcyclopentasiloxane (D5) (R2) dodecamethylcyclohexylsiloxane (D6) (R2)
UV filters	skin protection; product stability and durability	endocrine disruption (Schlumpf et al. 2004)	*3,4-methylbenzylidene camphor (R2)* benzophenone (R2) benzophenone-1 (R2) *benzophenone-2 (R2)* benzophenone-3 (R2) oxtinoxate (R2) *octadimethyl PABA (R2)*

[a] General use categories obtained from the NLM Hazardous Substance Data Bank and/or scientific literature
[b] Health effects have not necessarily been reported for all chemicals within the chemical class. Among the EDCs in this study, phthalates are the only chemical group for which there is supporting evidence of health effects from human studies. All asthma-associations are derived from human studies.
[c] Natural fragrances are readily available from plant materials, but can also be synthesized. Stereoisomer composition will differ for chemically synthesized materials. Our analysis did not determine whether these were synthesized or derived from plant materials.
R2 indicates chemicals added during the second round of sampling
Italicized chemicals were not detected in any sample

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Study design

170 Conventional products composited to represent 42 product types – increase generalizability

43 Alternative products analyzed individually – increase specificity

- *Limited ability to compare detection frequency and concentration between conventional and alternative*

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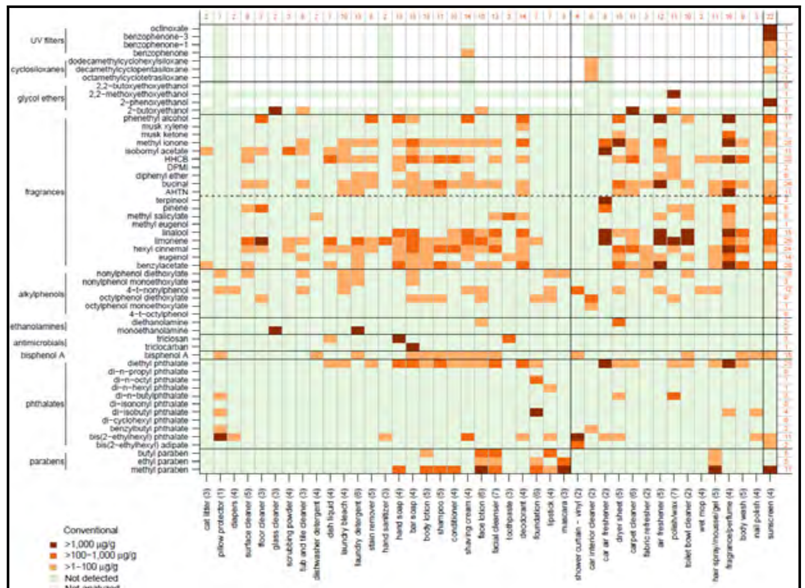
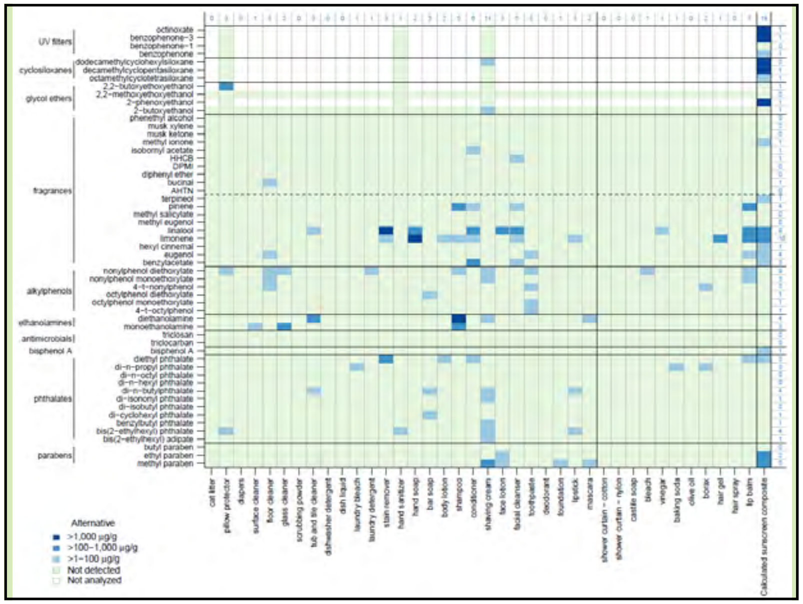
"Alternative" Product Criteria (labels did not indicate presence of) :

- ✓ parabens
- ✓ ethanolamines
- ✓ 1,4-dichlorobenzene
- ✓ nonionic surfactants
- ✓ fragrances ("natural" fragrances or essential oils permitted in some cases)
- ✓ tea tree oil, lavender
- ✓ triclosan, triclocarban, antimicrobial, antibacterial
- ✓ stain-resistant characteristics
- ✓ vinyl
- ✓ petroleum-based

and met selection criteria for a nation-wide natural food store





Summary of findings

- Detected 55 chemicals
  - All conventional
  - 32/43 alternative
- Highest concentrations: DEHP, fragrance, DEA, glycol ethers, UV filters
- Largest # and highest concentrations: sunscreens and fragranced products
- Vinyl products – up to 28% DEHP by weight
- Substitutions?

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Mixtures

- Zero to 22 in single product type
- Correlation analysis
- Surface cleaner + tub and tile + laundry detergent + bar soap + shampoo and conditioner + facial cleanser and lotion + toothpaste = 19 target chemicals

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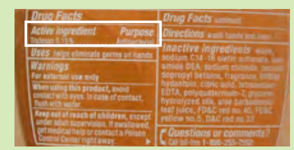
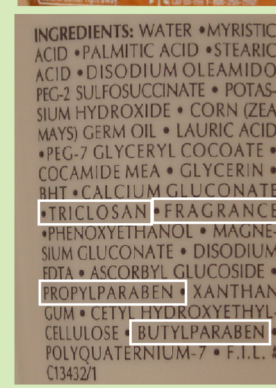
Label analysis

- It is possible to avoid some target chemicals through label reading but not all
- Generally not:
  - phthalates, ethanolamines, alkylphenols
- Generally yes:
  - parabens, antimicrobials, UV filters





Conclusions and Implications

- Exposures add up for multiple products
- Toxicological studies and risk assessment needed for mixtures
- For epidemiology, findings raise concerns
  - confounding from co-occurring chemicals (e.g. DEP a marker for fragrance)
  - misclassification due to variation in product composition (self-report)
- Labels facilitate consumer choice for regulated active ingredients, synthetic fragrance, and BPA
- Intervention to reduce exposure – focus on vinyl, fragranced products, reducing number of different products used, alternatives to sunscreen (e.g., shade)

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Review

Endocrine Disruptors and Asthma-Associated Chemicals in Consumer Products

- Link to article
- Fact Sheet
- Tips Card
- Product Names
- Video

The study was funded by the U.S. Centers for Disease Control and Prevention, the Goldman Fund, and Hurricane Voices Breast Cancer Foundation.

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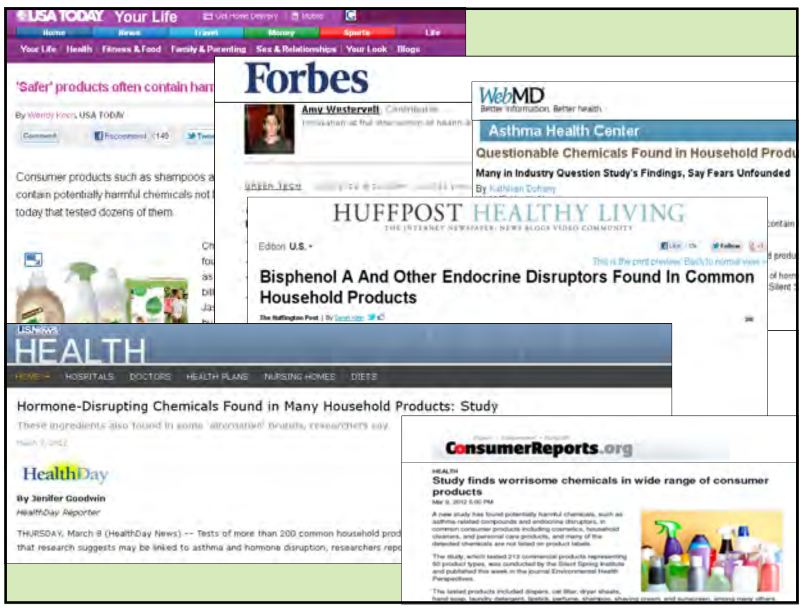

Top Tips

CHOOSE

✓ Fewer products

✓ Plant-based ingredients

✓ Plain water, baking soda and vinegar for cleaning

✓ Shade, hats and tightly woven fabric cover-ups for sun protection

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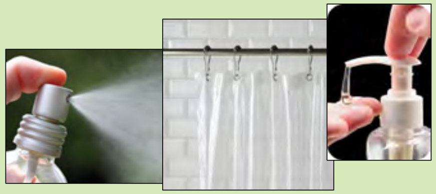
Top Tips



AVOID

- **Fragrances** in cleaning and personal care products
- **Vinyl products**, especially pillows and mattress-protectors
- **Antimicrobials** in soap, toothpaste and other products (watch out for “antibacterial,” “antimicrobial,” “triclosan” and triclocarban” on the label)

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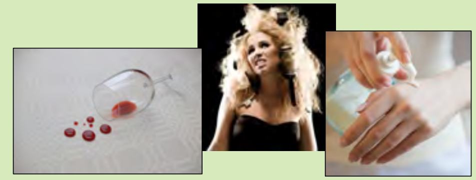
Top Tips



AVOID

- **Stain resistant** furniture sprays or clothing
- **Lavender** and **tea tree oil**
- **Parabens** in lotions, deodorants, shampoos and other cosmetics (look for “paraben-free” and watch out for “methylparaben,” “ethylparaben” and “butylparaben”)
- **Cyclosiloxanes** in suncreen and hair products (watch out for “cyclomethicone”)

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