RESEARCHING THE ENVIRONMENT AND WOMEN'S HEALTH

Emerging Contaminants in Cape Cod Private Drinking Water Wells

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Executive Summary

Overview

In February 2011, Silent Spring Institute tested 20 private drinking water wells in 7 towns on Cape Cod for emerging contaminants to learn more about the effect of septic systems and other sources of groundwater pollution on water quality on the Cape. Emerging contaminants include chemicals such as pharmaceuticals and consumer product chemicals that may have health effects but are not currently regulated or routinely studied in drinking water. This study is a follow-up to our 2010 study of emerging contaminants in Cape Cod public wells. We tested for 121 chemicals including pharmaceuticals, hormones, personal care products, perfluorinated chemicals, flame retardants and alkylphenols. Many of the target compounds have been found in other U.S. drinking water supplies and some are thought to be endocrine disrupting chemicals, which can mimic or interfere with the behavior of natural hormones.

A majority (85%) of samples contained emerging contaminants at parts per trillion levels. As in our public well study, these results show that chemicals in household and commercial wastewater can seep from septic systems into groundwater and make their way into drinking water. In general, results were similar in public and in private wells. Many of the same chemicals were detected in both studies, and maximum concentrations of these chemicals were generally similar. In both private and public Cape Cod drinking water wells, we found some compounds present at levels as high or higher than reported elsewhere in the US.

Our results demonstrate widespread impact of wastewater, primarily from septic systems, on Cape groundwater and drinking water. While there are no enforceable drinking water standards for emerging contaminants, health-based guideline values have been developed for four of the detected chemicals; levels in all samples were below guideline values. However, guideline values are not available for most of the chemicals we detected, and health effects of exposure to low levels of these types of chemicals, especially in complex mixtures, are not yet known.

Findings

- Of 121 emerging contaminants, 27 were detected at least once: 12 pharmaceuticals, 5 perfluorinated chemicals, 4 flame retardants, 2 hormones, 1 skin care product, 1 artificial sweetener, 1 insect repellent, and 1 plastics additive.
- The most frequently detected chemical was acesulfame, an artificial sweetener, which we found in 85% of wells. Four perfluorinated chemicals (PFOS, PFBS, PFHxS and PFHxA) were also found in at least 50% of wells. These perfluorinated chemicals are present in stain-resistant and nonstick coatings on paper and textiles, as well as in fire-fighting foams and various industrial processes. At least one of these perfluorinated chemicals has been largely phased out of consumer products due to health concerns. Perfluorinated chemicals were also commonly detected in Cape Cod public wells, in some cases at levels approaching health-based guidelines. These chemicals are associated with effects on thyroid hormones and growth and development in animal studies and effects on attention and behavior in children.
- Samples containing higher levels of nitrate and boron (markers of septic system contamination) and higher levels of acesulfame (an artificial sweetener) tended to have a larger number of emerging contaminants, and higher levels.
- For 4 of the 7 most frequently detected chemicals in public wells, maximum levels were similar in private wells (sulfamethoxazole, carbamazepine, meprobamate, TEP). The maximum PFOS level in a public well was more than 10 times higher than in any private well and likely originated from non-residential sources. Two of the most frequently detected chemicals in public wells were not detected in the private wells (phenytoin, TCPP).
- Compared to other drinking water studies, detected levels of most emerging contaminants were low to moderate, while others were relatively high. For three pharmaceuticals, sulfamethoxazole

(an antibiotic), carbamazepine (an epilepsy drug), and simvastatin (Zocor, a cholesterol-lowering drug), the highest levels in Cape Cod private wells were among the highest found in the U.S.

- These are among the first reported drinking water levels for four perfluorinated chemicals -- PFBS PFHpA, PFHxA, and PFHxS. While there is a health-based guideline value for PFBS, there have been few studies of the health effects of these chemicals, so there is limited context for interpreting this finding. We also detected the better-studied PFOS in both private and public drinking water wells on Cape Cod, and the highest level measured in a public well approached a health-based guidance value. The U.S. EPA has included PFOS, PFBS, PFHxS, and PFHpA on a list for future monitoring in public water supplies.
- We found little evidence of estrogen hormones or estrogenic activity in private well samples.

Implications

The health effects of exposure to low levels of these types of compounds, especially when they occur together in complex mixtures, are not known.

- Enforceable drinking water standards have not been developed for any of the emerging contaminants we found. Health-based guideline values were available for four detected chemicals (PFOS, PFBS, DEET, carbamazepine). No samples approached or exceeded these values, although PFOS levels in one of the public wells did approach the health guideline.
- Detected levels of most emerging contaminants ranged from 0.1 to 100 nanograms per liter (parts per trillion). For comparison, volatile organic compounds and other organic chemicals are typically regulated in drinking water at the parts per billion range (1000 nanograms per liter or higher). The highest pharmaceutical levels detected in drinking water samples were many orders of magnitude lower than the amounts associated with therapeutic doses. Direct contact with household products containing chemicals such as perfluorinated chemicals and flame retardants would likely lead to higher levels of exposure to these chemicals.
- Despite these reassurances, there are reasons to limit exposures to emerging contaminants through drinking water. Pharmaceuticals are biologically active in small quantities and are not intended for the general population, and some effects may occur at much lower doses than those used therapeutically. Exposures that occur at sensitive developmental stages (for instance, in fetuses and infants) may have effects at lower doses than exposures during other life stages. Furthermore, we have limited understanding of potential health effects of mixtures of pharmaceuticals and other chemicals at low levels.

Conclusions

Although the levels of pharmaceuticals, perfluorinated chemicals and other emerging contaminants in drinking water are not currently regulated, it is prudent to find ways to prevent discharges from septic systems and wastewater treatment plants from impacting drinking water. Building on efforts of Cape communities to protect drinking water quality, additional measures can reduce the impacts of wastewater on Cape drinking water supplies.

- To reduce chemical inputs into drinking water, Cape residents should check local guidelines for proper disposal of hazardous products and unused medications, use fewer and simpler cleaning chemicals, reduce their reliance on stain-resistant, antimicrobial, and fragranced products, maintain septic systems and support local efforts to protect groundwater.
- In areas where private wells have elevated nitrate levels, municipal wells installed in less developed areas will generally provide drinking water with fewer contaminants.
- Private well owners may want to test their water quality regularly and consider home filtration if their water shows signs of wastewater impact, such as nitrate levels above 0.5 mg/L.

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Introduction

Why did we do this study?

In recent years, traces of pharmaceuticals and other synthetic chemicals have been found in drinking water supplies throughout the United States. For example, in 2008 the Associated Press reported that the drinking water of 24 major metropolitan areas, serving 41 million Americans, contained trace levels of pharmaceuticals.[1] Pharmaceuticals, consumer product chemicals and other "emerging contaminants" in wastewater can make their way into drinking water when discharges from septic systems and wastewater treatment plants are released into groundwater, rivers and lakes. "Emerging contaminants" are chemicals whose presence in the environment has become more widely recognized in recent years through improved analytical measurement techniques but which are not currently regulated. Some of the chemicals found in contaminated drinking water have been shown to act as endocrine disrupting compounds (EDCs), chemicals that can mimic or disrupt the behavior of hormones in the body.

Drinking water on Cape Cod is vulnerable to contamination by household wastewater. The Cape's shallow unconfined aquifer contains porous sandy soils with low levels of organic matter that allow relatively fast movement of groundwater and limited breakdown of contaminants.[2] In recent decades, the Cape's growing population has put increasing stress on drinking water resources[3,4] and 85% of Cape residences rely on onsite wastewater treatment systems (including septic systems).[5] Previous studies by Silent Spring Institute have found pharmaceuticals, hormones, and other chemicals in groundwater downgradient of septic systems,[6,7] and a 2005 U.S. Geological Survey study found pharmaceuticals and organophosphate flame retardants in several Cape Cod drinking water wells (public, semi-public and private).[8] Silent Spring Institute detected pharmaceuticals and hormones in several Cape Cod ponds, especially downstream of more densely populated residential areas, suggesting septic systems as a source of these contaminants.[9] In 2009, Silent Spring Institute measured the levels of pharmaceuticals, consumer product chemicals, EDCs and other emerging contaminants in Cape Cod public drinking water supplies. We tested 20 public wells supplying water to 9 Cape water districts, mostly on the Upper and Mid-Cape, and tap water samples from 2 of these districts. Our results showed three-quarters of the wells tested contained detectable levels of at least one emerging contaminant and we found 18 of 92 emerging contaminants in at least one well. Samples with higher levels of nitrate and boron and wells in more heavily populated areas tended to have more emerging contaminants at higher levels.

Silent Spring Institute has been studying water quality on Cape Cod for over 10 years. Our goal is to understand whether there are environmental factors linked to the Cape's elevated incidence of breast cancer. One of our questions is whether EDCs and other contaminants in drinking water play a role. Previous research has suggested that there may be a link between exposure to certain EDCs and hormonally-active diseases such as breast cancer.[10,11] As part of Silent Spring Institute's Cape Cod Breast Cancer and Environment Study, an initial analysis used historical nitrate levels in drinking water as a tracer of contaminants from septic system or wastewater treatment plant discharges. This analysis did not show a link between higher nitrate drinking water and breast cancer risk.[3] However, nitrate data were not available far into the past and we could not estimate exposure for participants who lived off-Cape or used private wells. There have been few direct measurements of EDCs and other contaminants in Cape Cod drinking water supplies. A recent article by scientists at Boston University reported elevated breast cancer risk for women in the 1980s and early 1990s in Hyannis compared with other Upper Cape areas and associated this increase with contaminants in the Hyannis Water System supply.[12] These contaminants could include wastewater-related chemicals from the wastewater treatment plant in Barnstable, septic system discharges upgradient of the wells, and/or contaminants from commercial and industrial sources.

Study objectives

The goal of this new study was to measure the levels of pharmaceuticals and personal care products (PPCPs), EDCs and other emerging contaminants in Cape Cod private wells. Private wells serve 20% of Cape residents[13] and may be more vulnerable than public wells to contamination from septic systems. We compared the concentrations of emerging contaminants in Cape private wells with those found in our 2010 study of Cape public wells and in other U.S. drinking water sources. Our results illustrate the importance of continued efforts to protect the Cape's drinking water supplies and have implications for decisions about upgrading the Cape's drinking water and wastewater infrastructure.

Study design

Which wells did we test?

We tested water samples from 20 private wells located across Cape Cod. We tested 5 wells in Eastham, 5 in Wellfleet, 3 in Barnstable, 3 in Truro, 2 in Brewster, 1 in Falmouth and 1 in Sandwich. In selecting wells, we aimed to test wells with a range of likely impacts from septic systems, with an emphasis on wells that we thought would be moderately or highly impacted. We expected that wells most likely to be impacted by septic systems would have more emerging contaminants than wells less likely to be impacted by septic systems. We also aimed to include many wells from towns on the Lower Cape that rely heavily or entirely on private wells, while maintaining some geographic diversity by including several wells on the Upper and Mid-Cape. The wells we selected do not necessarily provide a representative sampling of the thousands of wells throughout Cape Cod.

We selected wells in two steps. In the first step, we recruited study volunteers through announcements in local media, at local libraries, and at public events; interviewed over 100 volunteers by phone; and selected 50 wells for a preliminary round of water quality testing. These wells were selected based on analysis of residential land use near each well, using GIS-based land use/land cover data from MassGIS and a simple method to estimate recharge areas for private wells (the area of land contributing water to a well).[14] This method incorporates information about typical groundwater flow rates and potential seasonal fluctuations in the direction of groundwater flow and pumping rates (Figure 1a). While actual recharge areas also depend on local groundwater flow, well depth and other factors (Figure 1b), this method provided a measure of how much local residential sources might affect each well. In the second step, we tested a water sample from each of these 50 wells for nitrate and boron, which are both markers of septic system impacts. Based on the nitrate and boron testing results, we chose 20 wells for emerging contaminants testing, with an emphasis on high nitrate wells and the goal of including wells from across the Cape. We collected samples from each of these 20 wells in February 2011. This report summarizes the findings from these 20 wells.

What did we test for?

We tested for 121 emerging contaminants, comprising:

- 60 pharmaceutically-active compounds (over-the-counter and prescription drugs, including 32 antibiotics, caffeine, nicotine and other pharmaceutically-active compounds)
- 9 hormones (naturally-occurring and synthetic)
- 14 perfluorinated chemicals (surfactants used in non-stick and stain-resistant consumer products, fire-fighting foams and some industrial processes)
- 8 alkylphenols (breakdown products of some detergent compounds)
- 16 organophosphate flame retardants (used as flame retardants and plasticizers in many household products)
- 8 herbicides, including 7 commonly used in lawn care
- 6 other chemicals

Some of these chemicals were included because of potential health concerns, such as endocrine disruption. Many have previously been found in other studies of U.S. drinking water supplies or wastewater. Some additional chemicals were included because they were measured by the laboratory using the same technique as other chemicals of interest. 90 of these chemicals were also tested in our study of Cape public wells in 2010.

We also measured levels of 8 commonly-tested chemicals and water quality parameters:

- nitrate
- total nitrogen
- total organic carbon
- boron
- sodium
- mercury
- copper (reported by the laboratory if detected above federal drinking water standard)
- lead (reported by the laboratory if detected above federal drinking water standard)

Nitrate, boron, total nitrogen, and total organic carbon are all markers of wastewater. In our study of public wells, higher levels of nitrate and boron were associated with more frequent detections and higher levels of emerging contaminants. Nitrate and total nitrogen come from human waste, as well as from fertilizers. Total organic carbon is found in human waste and can also come from natural sources such as decaying plant and animal material. Boron is used in many detergents and soaps, and also can enter groundwater from saltwater intrusion. We also measured sodium in order to estimate how much of the boron in well water sample may have come from salt water.

We also tested for three heavy metals. Lead and copper are typically found in drinking water because they can leach from household pipes, especially in acidic water. Mercury is found in many household products and can also come from industrial, commercial and natural sources.

Samples from 8 of the highest nitrate wells were tested for estrogenic activity. Estrogenic activity is a measure of the ability of a chemical or mixture of chemicals to produce a biological response similar to natural estrogens. Estrogenic activity tests can integrate the effects of all chemicals that are present in a sample, including “daughter” compounds that can form in the environment, many of which are poorly characterized with unknown health effects. Thus, estrogenicity testing may provide a better measure of the behavior of chemical mixtures in the human body.

How did we collect and test samples?

All water samples were collected in February 2011 by Silent Spring Institute research staff members with the assistance of trained volunteers. We also collected quality assurance/quality control (QA/QC) samples, including blanks and duplicates (Appendix 2). Because emerging contaminants are typically present at very low (parts per trillion) levels in drinking water, we took extensive precautions to avoid contaminating samples. All sampling bottles were handled only with clean gloved hands, and whenever possible, efforts were made to avoid potential household sources of the contaminants of interest.

Untreated water samples were collected before any household drinking water treatment, including acid neutralization and filtration. Prior to sample collection, each faucet or spigot was flushed for at least 10 minutes.

Emerging contaminants testing was conducted by the drinking water laboratory of Underwriters Laboratories Inc., based in Indiana, one of the few commercial laboratories that routinely measures emerging contaminants in drinking water. Total nitrogen and total organic carbon analyses were conducted at the Water Quality Laboratory of the Barnstable County Department of Health and Environment. Mercury analyses were carried out by the laboratory of Dr. Carl Lamborg at the Woods Hole Oceanographic Institution. Tests for total estrogenic activity were conducted in eight samples by Dr. Shane Snyder and Dr. Bob Arnold at University of Arizona.

Results and interpretation

What did we find?

Most of the private wells we tested on Cape Cod contained measurable levels of emerging contaminants, most likely coming from septic systems. Of the 20 wells we tested, 17 had detectable levels of at least one emerging contaminant.

- Of the 121 emerging contaminants that we tested for, we detected 27 in at least one water sample (Table 1). The detected chemicals included 12 pharmaceuticals (including 5 antibiotics), 5 perfluorinated chemicals, 4 flame retardants, 2 hormones, 1 skin care product, 1 artificial sweetener, 1 insect repellent, and 1 plastics additive (Figure 2). The majority (78%) of the 121 chemicals were not detected in any samples. See Appendix 1 for a complete list of chemicals included in this study.
- The number of emerging contaminants that were detected in an individual sample varied from zero to 13.
  - 3 samples had no detectable emerging contaminants
  - 4 samples had detectable levels of 1 or 2 emerging contaminants
  - 8 samples had detectable levels of 4 to 8 emerging contaminants
  - 5 samples had detectable levels of 10 to 13 emerging contaminants

Many perfluorinated chemicals were detected in Cape Cod groundwater. Perfluorinated chemicals were the most commonly detected contaminants of concern; their frequent detection suggests that they are ubiquitous groundwater contaminants on the Cape. Due to concerns over their persistence and potential health effects, PFOS and other perfluorinated chemicals with long carbon chains have been phased out of many consumer products.[15-17] Common replacements include perfluorinated chemicals with shorter carbon chains, such as PFBS, which are less likely to bioaccumulate. We found PFOS and PFBS in 11 wells each, and we found 3 perfluorinated chemicals of intermediate length in 6 to 11 wells each. Concentrations of individual perfluorinated chemicals, as well as the total concentration of detected perfluorinated chemicals, were well correlated with concentrations of nitrate, boron, and acesulfame, suggesting that wastewater is likely the major source of these chemicals into the tested wells.

Measurements of perfluorinated chemicals in blood indicate that most Americans are exposed to these chemicals, although the major sources of exposure are not well understood.[16,18] Relationships between levels of perfluorinated chemicals in blood and specific products are difficult to establish, in part because there is little publicly available information about production methods. While some perfluorinated chemicals are intentionally added to products, some can be formed through poorly-understood chemical transformations from related chemicals during production and use.[15]

We found no estrogens, low levels of other hormones, and limited evidence of estrogen-mimicking EDCs, in private well water on the Cape. Because we want to gain a better understanding of potential environmental factors that might affect breast cancer on Cape Cod, Silent Spring Institute has focused on identifying exposure to hormones and other endocrine disrupting compounds, especially those that disrupt estrogen and progesterone signaling. Many of the factors known to affect breast cancer risk (e.g., age of first menstruation, number of full-term pregnancies, hormone replacement therapy) reflect the levels of estrogen and progesterone in a woman's body, so there is concern that that estrogenic (estrogen-mimicking) or other hormonally active environmental chemicals may also increase breast cancer risk.[10,11] Among the hormones we tested for, we did not detect the six natural or synthetic estrogens. We did detect relatively low levels (less than 0.1 ng/L) of two hormones: progesterone, a female reproductive hormone (1 well) and cis-testosterone, a male reproductive hormone (3 wells).

We tested for estrogenic activity in 8 of the wells with the highest nitrate concentrations. Estrogenic activity is a measurement of how much a sample might act like estrogen in the body. Laboratories measure estrogenic activity in drinking water by exposing estrogen-sensitive cells to a water sample and comparing how the cells respond to the sample against how they respond to a known concentration of estrogen. In this study, the laboratory reported estrogenic activity in terms of how much of the strong synthetic estrogen 17α-ethinylestradiol would cause the same response. In all 8 samples tested, estrogenic activity was below the detection limit (equivalent to 0.32 ng/L 17α-ethinylestradiol).

We also tested for estrogenic chemicals, including alkylphenols and bisphenol A. We did not find nonylphenol and octylphenol, two alkylphenols that are weak estrogen mimics formed from the breakdown of certain surfactants, nor nonylphenol ethoxylates that can degrade into nonylphenols. We found the estrogenic plastics additive bisphenol A in only one sample.

Similarly, in our public well study, we found no hormones in any well and trace levels of one alkylphenol (nonylphenol) in just one well. Some studies on the Cape have demonstrated breakdown of these chemicals as they move through groundwater,[19] and septic systems with leach fields may effectively reduce the levels of hormones and alkylphenols.[20,21] However, previous work by Silent Spring Institute and others on Cape Cod has shown the persistence of hormones and alkylphenols in Cape groundwater,[6,7] and several Cape Cod ponds contained detectable levels of several hormones.[9]

There is limited information on the ability of most of the tested chemicals to act as endocrine disruptors. As the importance of endocrine disruption becomes more widely recognized, better screening tools are needed to identify which chemicals have the potential to act as EDCs.

Some of the detected chemicals have been associated with other potential health effects. Many of the perfluorinated chemicals detected have been shown in laboratory tests to affect thyroid hormone pathways and cholesterol metabolism.[22,23,24] High body levels of perfluorinated chemicals are also associated with effects on attention and behavior in children in multiple studies.[25,26] There are concerns about neurotoxicity and carcinogenicity of organophosphate flame retardants,[27-29] but relevant testing for the flame retardants we detected is limited. These effects have been seen primarily in animal studies at much higher levels of exposure than are likely from drinking tap water, and the levels we detected are below available health-based guidelines.

We identified several useful indicators of emerging contaminants. We wanted to identify less expensive approaches that can be used to predict levels of emerging contaminants in Cape Cod groundwater, which are expensive to measure. Wells with higher levels of nitrate, boron and the artificial sweetener acesulfame tended to have higher numbers of detectable emerging contaminants, at higher levels (Table 3, Figure 3(a-b)). Nitrate and boron were also found to be good indicators of the presence of emerging contaminants in our study of public wells.

Among the emerging contaminants, acesulfame, an artificial sweetener, was our most frequently-detected chemical, found in 17 of 20 wells (85%). Acesulfame is a sensitive marker of wastewater impact because there are no natural sources, it is present at relatively high levels in wastewater (up to 46,000 ng/L) and it does not readily break down in the environment.[30] Wells with higher levels of acesulfame tended to have more chemicals detected (Figure 3). For instance, we detected on average less than one chemical in wells with <1 ng/L acesulfame and more than 10 chemicals in wells with >1000 ng/L acesulfame.

Compared to chemical markers of wastewater impact, residential land use density was less strongly, but still significantly, associated with the presence of emerging contaminants. Using the extent of residential development within estimated recharge areas for each well, we found that the extent and density of residential development was related to the number and total concentration of detected emerging contaminants and the number of detected pharmaceuticals (Figure 3(c)). Future work using more sophisticated groundwater models to estimate well recharge areas may do a better job at relating land use to the presence of emerging contaminants, since the method we used does not incorporate the complexities of groundwater flow. For instance, depending on the predominant direction of groundwater flow and the well depth, the actual location of each recharge area can vary considerably (Figure 1). In some cases, a well's recharge area may be hundreds, and potentially thousands, of feet away,[31] making it difficult to determine the exact area of land that influences a particular well. The direction of groundwater flow also can fluctuate seasonally.

Based on well depth information for 17 wells, we found that deeper wells tended to have fewer emerging contaminants and lower concentrations, although these relationships were not statistically significant. In general, deeper wells tend to be better protected from pollution sources because groundwater must travel longer to reach them, allowing more time for contaminant breakdown.

We also tested for total organic carbon (TOC), which is a relevant water quality parameter in Massachusetts, where wastewater treatment plants are required to meet a TOC limit of 3 mg/L for groundwater discharges of effluent within recharge areas for public wells.[32] We had limited ability to evaluate the relationship between TOC and the presence of emerging contaminants, since only 5 of the 20 wells (25%) contained detectable levels of TOC (above 1 mg/L). Wells with TOC above 1 mg/L tended to have more emerging contaminants, and higher total concentrations of emerging contaminants, but the differences were not consistent or statistically significant.

How do private well results compare with public well results?

There are similarities in the most frequently detected chemicals in both public and private wells (Figure 4). The four chemicals that we detected most frequently in public wells (sulfamethoxazole, PFOS, carbamazepine, and TEP) were all detected in at least one private well. Sulfamethoxazole and carbamazepine were the most commonly detected pharmaceuticals in both public and private wells. With the exception of PFOS, the highest concentrations in public wells were similar to those in private wells. The highest level of PFOS in a public well was more than 10 times the highest level we found in a private well, and appeared to originate from sources other than domestic wastewater. Two chemicals found in 4 (20%) of the public wells were not found in any of the private wells: the flame retardant TCPP and the pharmaceutical phenytoin (Dilantin).

Further comparisons between our findings for public and private wells are limited because of differences between the analytes in the two studies, the small number of wells sampled in each study, and the fact that neither set is necessarily representative of all public or private wells on the Cape. Most of the private wells in this study were on the lower Cape, while most of the public wells were on the Upper and Mid-Cape. In the private well samples, we tested for 33 chemicals that we did not test for in public wells, including 12 perfluorinated chemicals. In addition, detection limits were lower in the private well testing for most compounds, so it is difficult to compare detection frequencies between the two studies.

How do these results compare with health guidelines and other studies?

Nitrate levels in three wells, and sodium in ten wells, exceeded guideline values. Levels of mercury, lead, and copper did not exceed standards or guidance values in any well. The nitrate level in one well was above the federal drinking water standard of 10 mg/L, and 2 additional wells had nitrate above the Cape Cod Commission's guideline value of 5 mg/L. No samples exceeded drinking water standards or health-based guideline values for boron, mercury, lead or copper. While there is currently no drinking water standard for sodium, half of the private wells exceeded the guideline value for people on a low sodium diet (20 mg/L).

We compared levels of emerging contaminants detected in this study with health-based guidelines and with the results of other U.S. drinking water studies. There are currently no federal or Massachusetts drinking water regulations for any of the emerging contaminants that we detected. Public water suppliers and private well owners are not required to test for any of the emerging contaminants in our study.

In some cases, state and federal agencies have developed health-based guidelines, which incorporate information about health effects from animal and human studies. These guideline values are designed to indicate levels in drinking water that pose little to no health risk, although it is possible that there can be health effects below these guideline values if they do not adequately protect sensitive populations or account for exposures to many chemicals together. For most of the chemicals we detected, there are no health-based guidelines, so we also compared Cape Cod results with the results of previous measurements of emerging contaminants in untreated and treated drinking water throughout the U.S.

Health-based drinking water guidelines are available for only four of the emerging contaminants detected in private drinking water wells on Cape Cod. No samples exceeded the health-based guidelines for these chemicals. The highest PFOS level we detected (7 ng/L) was well below the U.S. Environmental Protection Agency's short-term provisional health advisory value of 200 ng/L[33] and the Minnesota Department of Health's health-based value of 300 ng/L.[34] The highest PFBS level we detected (23 ng/L) was well below the Minnesota Department of Health health-based value of 7000 ng/L.[35] The highest DEET level we detected (4 ng/L) was well below the Minnesota Department of Health's health-based value of 200,000 ng/L.[36] The highest carbamazepine level we detected (62 ng/L) was well below the Minnesota Department of Health's health-based value of 40,000 ng/L.[37]

Compared to other drinking water studies, the levels found for many emerging contaminants were low to moderate. However, for several chemicals, the highest levels in Cape private wells were among the highest in the U.S. We compared our results to those from other studies of raw (untreated) drinking water in the U.S. (Table 1). Only one of these studies included samples from private wells. Some of the chemicals that we detected have not been tested in any studies of raw U.S. drinking water; for these chemicals, we included comparison studies that tested tap water and studies conducted in Canada or Europe, if available.

Most of the chemicals we detected were present at relatively low to moderate levels compared to other studies. However, our highest levels of three pharmaceuticals and two perfluorinated chemicals were among the highest reported in U.S. drinking water. Sulfamethoxazole and carbamazepine levels in a few wells were among the highest found compared to several other studies of raw U.S. drinking water. We detected simvastatin (a cholesterol-lowering drug) in just one well, at a level (14 ng/L) that exceeded levels in two other studies in which all samples were below their respective detection limits (<0.25 ng/L and <1 ng/L).

The perfluorinated chemicals PFBS and PFHxS were detected in at least one well at levels higher than in any study reviewed, although very limited comparison data were available. These chemicals are much less well studied than two related perfluorinated chemicals, PFOS and PFOA, but are gaining recognition as contaminants of concern. PFBS, PFHxS, PFHpA, and PFOS (all detected in this study), along with PFOA and PFNA, have been included on EPA's Unregulated Contaminant Monitoring Rule list. As a result, many public drinking water suppliers will be required to test for these chemicals starting in 2013, which will provide valuable information about how widespread these chemicals are in drinking water.

The health effects of exposure to low levels of emerging contaminants, especially in complex mixtures, are not known. The presence of a chemical alone does not necessarily mean that it is harmful, and anticipating the effects of low level exposures to chemicals such as pharmaceuticals and EDCs in humans is difficult.

- Almost all emerging contaminant levels that we detected were well below 1000 ng/L (1 part per billion, or ppb). Other organic (carbon-containing) chemicals, such as volatile organic compounds, are typically regulated in drinking water above 1000 ng/L. For pharmaceuticals, even the highest levels detected in well water samples were many orders of magnitude lower than the amounts found in a typical dose of a medicine. For chemicals associated with household products, such as perfluorinated chemicals and organophosphate flame retardants, direct contact with products containing these chemicals would likely lead to much higher levels of exposure.

- However, there are reasons to limit exposures to these chemicals through drinking water. Pharmaceuticals are biologically active in small quantities and are not intended for the general population. In particular, exposures that occur at sensitive developmental stages (for instance, in fetuses and infants) may have effects at lower doses than during other life stages. For example, a recent study shows that the common pain-reliever acetaminophen affects testosterone production at levels 100 times lower than the typical dose and also reports reproductive problems in boys whose mothers took this pain-reliever while pregnant.[38] Furthermore, while people are exposed to complex mixtures of chemicals, most studies focus on one chemical at a time, so we have limited understanding of the potential health effects of mixtures of pharmaceuticals and other chemicals at low levels. Some preliminary studies using human cell lines have shown that mixtures of low levels of pharmaceuticals can cause effects that were not observed for these chemicals individually.[39] In addition, some pharmaceuticals can be biologically active (for instance, in fish) at very low levels -- even as low as 5 ng/L -- and often have side effects that are not taken into account when considering only intended doses. More information about the effects of some of these chemicals in laboratory animal studies can be found in Table 4.

Future drinking water regulations may include some of the chemicals detected in Cape drinking water supplies. The EPA currently regulates around 90 contaminants in drinking water. In the future, the EPA may regulate some of these emerging contaminants in drinking water. The EPA's most recent Candidate Contaminant List (CCL3, the list of chemicals being considered for future regulations) included one chemical we detected, PFOS, as well as several hormones and an antibiotic that we tested for but did not detect. Drinking water regulations are established after extensive scientific studies to understand the health effects of chemicals and the levels that may be harmful. Much of this information is lacking for emerging contaminants.

Keep in mind

Drinking water is just one pathway by which people are exposed to chemicals. Perfluorinated chemicals and organophosphate flame retardants are often found in clothing, furniture and other household products, so touching these products directly or inhaling household dust and air may potentially be much larger routes of exposure. In addition, exposure to perfluorinated compounds can occur through eating food that has come into contact with cookware and packaging containing nonstick additives. Household exposures to most of these chemicals are not well understood; in fact, one of Silent Spring Institute's research aims is to measure exposures to these types of chemicals and others within people's homes.

This study tested a small number of wells at a single point in time. Although our results indicate the presence of many emerging contaminants in Cape groundwater used for drinking, they may not reflect the overall condition of the thousands of private wells on Cape Cod. Given the small number of private wells tested, we cannot generalize findings to specific towns or regions of the Cape. In addition, chemical levels in any one well may change over time. In addition to long-term changes caused by the Cape's growing population, there can be seasonal differences in groundwater movement caused by fluctuations in precipitation, rates of pumping for drinking water and discharges from septic systems and wastewater treatment plants.

Whereas the nitrate levels in the public wells we tested in 2009 were generally representative of the overall distribution of wells within the participating water districts, the private wells we tested may be relatively more impacted by septic systems than overall private wells across Cape Cod. Appropriate comparison data for water quality in private wells are more difficult to obtain. Compared to around 1600 private wells tested in Truro, Wellfleet, and Eastham from 1985-1994,[40] the wells in our current study had a higher median nitrate value (2.3 mg/L versus 1.2 mg/L) and a higher proportion of wells above 5 mg/L (15% versus 10%). However, nitrate levels in Cape groundwater have generally increased over the past 20 years.

We tested untreated drinking water prior to filtration or other drinking water treatment. Chemical levels in tap water in these homes may be different depending on the types of treatment used.

What you can do

If you are concerned about contaminants in your drinking water, you may wish to install a home water filtration system. In general, filtration products that contain a solid carbon block filter have been shown to effectively reduce levels of many types of organic contaminants, although results will be different for each individual chemical. Filter pitchers that contain granular activated carbon will also remove organic contaminants. Some water filters are independently tested for dozens of organic contaminants to demonstrate their effectiveness, although the specific emerging contaminants that we measured are not routinely tested. Proper maintenance of home filtration systems is important. Improper use, for example not changing filters frequently enough, can lead to pathogens and other contaminants being released into the filtered water.

While some people drink bottled water as an alternative to tap water, the levels of emerging contaminants in bottled drinking water are not known, and regulatory monitoring of bottled water is less extensive than for public water supplies. There is no routine testing for emerging contaminants in bottled water and there are no published reports of measurements of pharmaceuticals and personal care products, EDCs and other chemicals in bottled water. While some bottled water comes from pristine water sources, some is simply tap water that may or may not be treated to remove chemicals. Furthermore, bottled water sits for extended periods of time in plastic containers, which may release chemicals into the water. Finally, the production of bottled water is far more resource-intensive than the sustainable use of local groundwater.

Ultimately, reducing the levels of pollutants in Cape Cod drinking water will require a concerted effort to reduce the amount of chemicals released into the Cape's groundwater aquifer and increased measures to protect drinking water supplies. Here are some steps you can take:

- Properly dispose of unused and expired medications. With the exception of a small number of controlled substances, most medications should not be flushed. The U.S. FDA provides guidelines (see "Additional Information" section) for consumers on proper disposal of medicines. Ask your pharmacy or town Board of Health about local programs for unwanted medications, and encourage local officials to create and publicize such programs. To reduce the amount of unwanted medications in your home, buy only what you will use and ask your doctor for trial sizes of new medications. Keep in mind that the majority of pharmaceuticals in wastewater are thought to come from excretion when people take their medications as directed, rather than from flushing.
- Consider purchasing household products, clothing and furnishings made from natural fibers and without chemical additives such as stain-resistant coatings, antimicrobials, flame retardants, and fragrances. Avoid harmful chemicals in your garden and lawn.

- Avoid dumping hazardous chemicals in your sink, on the ground or into storm sewers. Ask your town for information about hazardous waste collection days.
- Have your septic system regularly inspected and pumped. The Massachusetts Department of Environmental Protection (MassDEP) recommends pumping septic systems every 1-3 years.
- Support efforts to protect the Cape's shallow sole source aquifer from wastewater contamination, especially from septic systems. Installing sewers or advanced onsite treatment, especially in heavily developed areas, may prevent contaminants in septic system discharges from getting into drinking water.
- Support efforts to promote more thorough testing of chemicals before they go into production. Chemicals are present in wastewater because they are present in consumer products. However, many of these chemicals have not been thoroughly tested to understand their health effects.

If you want more information, please contact Silent Spring Institute at info@silentspring.org or 617-332-4288.

Next steps

Given the importance of septic systems as sources of groundwater pollutants and the obstacles to widespread sewering, the identification or development of new or modified onsite wastewater treatment systems has great potential to reduce the extent of groundwater contamination. In conjunction with the Massachusetts Alternative Septic System Test Center, Silent Spring Institute is currently developing plans to quantify the removal or breakdown of many emerging contaminants in standard Title V septic systems and alternative onsite treatment systems.

Previous Silent Spring Institute research demonstrated the presence of hormones and pharmaceuticals in Cape Cod ponds due to high density of septic systems upgradient of the ponds. Additional studies of fish populations in Cape ponds, which are fed almost entirely by groundwater, could evaluate whether these chemicals are causing endocrine disruption in native fish populations.

Additional information

Silent Spring Institute

- Cape Cod water research: www.silentspring.org/our-research/water-research

Information for private well owners:

- Private well information from the MA Department of Environmental Protection: http://www.mass.gov/dep/water/drinking/privatew.htm
- Fact sheets on private wells from the University of Massachusetts Extension Service: www.umass.edu/nrec/watershed_water_quality/watershed_online_docs.html
- Home water treatment systems: www.umass.edu/nrec/watershed_water_quality/well-water-fact-sheets-pdf/treatmentquestions.pdf
- Barnstable County Department Of Health and Environment Water Quality Laboratory: www.barnstablecountyhealth.org/water-quality-laboratory

General information about pharmaceuticals and personal care products (PPCPs):

- U.S. Environmental Protection Agency: www.epa.gov/ppcp
- MA Dept. of Environmental Protection: www.mass.gov/dep/toxics/stypes/ppcpedc.htm
- U.S. Geological Survey: toxics.usgs.gov/regional/emc

Associated Press series on pharmaceuticals in drinking water

- Main story: hosted.ap.org/specials/interactives/pharmawater_site
- Results for 28 cities: hosted.ap.org/specials/interactives/pharmawater_site

Proper disposal of medications:

- Barnstable County Hazardous Materials Program: http://town.barnstable.ma.us/WaterSupply/medicationdisposal.pdf
- White House Office of National Drug Control Policy: www.whitehousedrugpolicy.gov/publications/pdf/prescrip_disposal.pdf
- U.S. Food and Drug Administration (FDA): www.fda.gov/ForConsumers/ConsumerUpdates/ucm101653.htm

Chemical testing policies:

- Safer Chemicals, Healthy Families: www.saferchemicals.org

General information about the Cape Cod Aquifer:

- www.capecodgroundwater.org/Cape_Cod_Aquifer.html

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TABLES, FIGURES AND APPENDICES

Table 1. Summary of emerging contaminants detected in 20 Cape Cod private drinking water wells sampled in February 2011.

Chemical name	Abbreviation	Detection limit (ng/L)	Number of times detected out of 20	Maximum concentration detected (ng/L)	Maximum concentration in public wells (ng/L)* (2010)	Maximum concentrations in other U.S. drinking water (ng/L)**	Health-based guideline values (ng/L)***
Pharmaceuticals – antibiotics							
monensin	Mon	0.52	1 (5%)	0.8J	ND (<1)	1.4[f], 2.4[h]†	NA
sulfachloropyridazine	SulfCP	0.58	2 (10%)	0.7J	ND (<5)	<5[f]	NA
sulfamethoxazole	SulfMX	0.1	9 (45%)	60	113	2[h]†, 12[f], 41[d], 58[k], 110[b], 150[i]	NA
sulfathiazole	SulfTZ	0.27	1 (5%)	0.2J	ND (<1)	<5[f], <100[d]	NA
trimethoprim	Trim	0.1	1 (5%)	1	0.7	<13[k], 1[h]†, 4[f], 11[b], 24.6[d], 580[i]	NA
Pharmaceuticals – non-antibiotics							
antipyrine	Antip	0.83	1 (5%)	2	1	<1[f]	NA
carbamazepine	Carb	0.068	5 (25%)	62	72	2[h]†, 5.3[k], 9[f], 51[b], 156[e], 190[d]	40,000
cotinine	Cot	0.59	1 (5%)	1	ND (<1)	<14[k], 12[f], 60[i], 102[d]	NA
gemfibrozil	Gem	0.15	1 (5%)	0.3J	1.2	<13[k], <15[d], 4[h]†, 17[f], 24[b]	NA
meprobamate	Mep	0.1	3 (15%)	2	5.4	73[b]	NA
primidone	Prim	2.1	2 (10%)	9	ND (<5)	35[e]	NA
simvastatin	Simv	3	1 (5%)	14	ND (<5)	<0.25[b], <1[f]	NA
Perfluorinated chemicals							
perfluorobutanesulfonic acid	PFBS	0.22	11 (55%)	23	--	1[h]	7000
perfluoroheptanoic acid	PFHpA	0.25	6 (30%)	1J	--	18[c]‡	NA
perfluorohexanesulfonic acid	PFHxS	0.33	11 (55%)	41	--	8.6[c]‡, 29[g]	NA
perfluorohexanoic acid	PFHxA	0.16	10 (50%)	2	--	5.3[c]‡, 12[g]	NA
perfluorooctanesulfonic acid	PFOS	0.24	11 (55%)	7	97	16[h], 41[g], 58[c]‡	200, 300

Chemical name	Abbreviation	Detection limit (ng/L)	Number of times detected out of 20	Maximum concentration detected (ng/L)	Maximum concentration in public wells (ng/L)* (2010)	Maximum concentrations in other U.S. drinking water (ng/L)**	Health-based guideline values (ng/L)***
Organophosphate flame retardants							
2-ethylhexyldiphenyl phosphate	2-EHDP	1.5	2 (10%)	18	ND (<10)	NA	NA
tributyl phosphate	TBP	5.1	1 (5%)	11	ND (<10)	62[j]‡, 190[k], 740[d]	NA
triethyl phosphate	TEP	10	1 (5%)	38	15	1[a]‡, 23[j]‡	NA
triphenyl phosphate	TPP	1.5	1 (5%)	14	ND (<10)	8.6[j]‡ 46[k], 67[d]	NA
Hormones							
cis-testosterone	Test	0.029	1 (5%)	0.04J	ND (<0.1)	NA	NA
progesterone	Prog	0.028	3 (15%)	0.04J	ND (<0.1)	3.1[b]	NA
Other							
acesulfame	Ace	0.42	17 (85%)	5300	--	NA	NA
bisphenol A	BPA	2.5	1 (5%)	4J	ND (<10)	<1000[k], 14[b], 1900[d], 2000[h]	NA
DEET	DEET	0.67	3 (15%)	4J	6	16[f], 74[k], 110[b], 410[d]	200,000
salicylic acid	Sal	15	3 (15%)	30J	(<50)	NA	NA

Definitions and abbreviations

- Detection limit = The lowest level of a chemical that can be detected using a chemical testing method.
- ng/L = nanograms per liter, also parts per trillion. A nanogram is one-billionth of one gram.
- J = chemical was detected above the detection limit but below the reporting limit. This concentration should be considered approximate.
- NA = not available
- ND = not detected
- -- = not tested in public wells

Notes

* Most chemicals had higher detection limits in our study of public wells than in private wells. Chemicals that were tested for but not detected in public wells have their detection limits in parentheses.

** Unless otherwise noted, these concentrations reflect raw (untreated) drinking water sources. Includes both groundwater and surface water sources.

*** See text for references for health-based guideline values

† Tabe et al., 2010 includes drinking water from the U.S. and Canada.

‡ Bacaloni et al 2008, Ericson et al 2009, and Williams et al 1981 were all conducted either in Canada or in Europe, and all tested either finished tap water or groundwater that was not clearly identified as drinking water.

References for Table 1

[a] **Bacaloni A and others, 2008.** Occurrence of organophosphorus flame retardant and plasticizers in three volcanic lakes of central Italy. *Environmental Science & Technology.* 42:1898-1903.

This study tested water from three lakes and nine groundwater wells in Italy for a range of organophosphate flame retardants. All of the locations tested in this study were remote, with possible impacts from nearby small towns, agricultural activities, and tourism. Only the results for TEP in groundwater are presented for these comparisons.

[b] **Benotti MJ and others, 2009.** Pharmaceuticals and endocrine disrupting compounds in U.S. drinking water. *Environmental Science & Technology*. 43:597-603.

This study included 19 large drinking water treatment plants serving 28 million people, including 18 surface water sources and 1 groundwater source. Raw (untreated), finished (treated) and tap water samples were tested for 51 emerging contaminants. Only results from raw water samples are presented.

[c] **Ericson I and others, 2009.** Levels of perfluorinated chemicals in municipal drinking water from Catalonia, Spain: Public health implications. *Archives of Environmental Contamination & Toxicology*. 57:631-638.

This study tested tap water (treated) samples from 40 locations in Spain for 13 perfluorinated chemicals.

[d] **Focazio MJ and others, 2008.** A national reconnaissance for pharmaceuticals and other organic wastewater contaminants in the United States--II) Untreated drinking water sources. *Science of the Total Environment*. 402:201-216.

This study tested 74 water supplies that ranged in size from very small to very large and included 49 surface water sources and 25 groundwater sources. Samples were tested for 100 emerging contaminants. This study included results for raw (untreated) water samples only.

[e] **Guo YC and SW Krasner, 2009.** Occurrence of primidone, carbamazepine, caffeine, and precursors of *N*-nitrosodimethylamine in drinking water sources impacted by wastewater. *Journal of the American Water Resources Association*. 45:58-67.

This study tested source waters for 7 water supplies in 5 U.S. states, all of which used surface water sources. Samples were tested for 3 pharmaceuticals. Only results from raw water samples are presented.

[f] **Illinois Environmental Protection Agency, 2008.** Report on Pharmaceuticals and Personal Care Products in Illinois Drinking Water. Bureau of Water, Illinois EPA.

This study tested raw (untreated) and finished (treated) samples from 5 water supplies in the Chicago area, all of which used surface water sources. Samples were tested for 56 pharmaceuticals and personal care products. Only results from raw water samples are presented.

[g] **Quiñones O and SA Snyder, 2009.** Occurrence of perfluoroalkyl carboxylates and sulfonates in drinking water utilities and related waters from the United States. *Environmental Science & Technology*. 43:9089-9095.

This study tested raw (untreated) and finished (treated) samples for 8 perfluorinated chemicals at 7 drinking water treatment plants with varying levels of wastewater impact. Only results for raw water samples are presented. For each treatment plant, multiple samples were collected over the course of one year, which were averaged in these comparisons.

References for Table 1 (continued)

[h] **Tabe S and others, 2010.** Occurrence and removal of PPCPs and EDCs in the Detroit River watershed. *Water Practice & Technology.* 5:1. doi:10.2166/WPT.2010.015

This study tested for 51 pharmaceuticals, personal care products and endocrine disrupting compounds in drinking water treatment plants in Michigan and Ontario, in wastewater samples and in the Detroit River. Only results from untreated drinking water samples are presented.

[i] **Verstraeten IM and others, 2005.** Use of tracers and isotopes to evaluate vulnerability of water in domestic wells to septic waste. *Ground Water Monitoring & Remediation*. 25:107-117.

This study tested for antibiotics and other pharmaceuticals in raw (untreated) samples from 25 private drinking water wells in Nebraska.

[j] **Williams DT and others, 1981**. A national survey of tri(haloalkyl)-, trialkyl-, and triarylphosphates in Canadian drinking water. *Bulletin of Environmental Contamination & Toxicology*. 27:450-457.

This study tested finished drinking water in 29 cities and towns throughout Canada in summer and winter.

[k] **Zimmerman MJ, 2005.** *Occurrence of Organic Wastewater Contaminants, Pharmaceuticals, and Personal Care Products in Selected Water Supplies, Cape Cod, Massachusetts, June 2004*. USGS Open-file Report 2005-1206.

This study tested 8 wells on Cape Cod: 3 public, one semi-public and 4 private wells. Samples were tested for 85 emerging contaminants. Results are provided for raw water samples only. This study also included measurements of these chemicals in monitoring wells impacted by a wastewater treatment plant, in a septic system leachfield and in a recirculating sand filter system.

Table 2. Summary of commonly-tested chemicals in 20 Cape Cod private drinking water wells sampled in February 2011.

	Detection limit	Maximum concentration in private wells	Maximum concentration in public wells (2010)	Drinking water standards or health-based guideline values
Markers of wastewater impact				
boron	0.5 µg/L	250 µg/L	37 µg/L	2000 µg/L (children)[b] 5000 µg/L (adults)[b]
nitrate	0.01 mg/L	11 mg/L	5.3 mg/L	10 mg/L[c]
total organic carbon	1 mg/L	6.4 mg/L	--	NA
total nitrogen	0.5 mg/L	13 mg/L	--	NA
Metals				
copper	1300 µg/L[a]	ND	--	1300 µg/L[d]
lead	15 µg/L[a]	ND	--	15 µg/L[d]
mercury	0.01 ng/L	8.5 ng/L	--	2000 ng/L[c]
sodium	0.002 mg/L	45 mg/L	--	20 mg/L[e]

Definitions and abbreviations

- Detection limit = The lowest level of a chemical that can be detected using a chemical testing method
- ng/L = nanograms per liter, also parts per trillion. A nanogram is one-billionth of one gram.
- µg/L = micrograms per liter, also a part per billion. A microgram is one-millionth of one gram.
- mg/L = milligrams per liter, also a part per million. A milligram is one-thousandth of one gram.
- -- = not tested in public wells
- NA = not available
- ND = not detected

Notes

[a] For copper and lead, the laboratory only reported values above the drinking water standard
[b] EPA Longer Term Health Advisory Level, which is a health-based guideline value
[c] EPA Maximum Contaminant Level (MCL), which is an enforceable drinking water standard
[d] EPA Action Level, which is an enforceable drinking water standard
[e] EPA Guidance Value for low sodium diets

Table 3. Average number of emerging contaminants detected in private wells is higher in wells with higher levels of nitrate. Range of values is provided in parentheses. The federal drinking water standard is 10 mg/L, and the Cape Cod Commission (CCC) has developed a guideline value of 5 mg/L.

	number of samples	**average number of compounds (range)**
<0.5 mg/L (minimal impact)	5	2.2 (0 to 6)
0.5 to 2.5 mg/L (moderate impact)	5	5 (2 to 10)
2.5 to 5 mg/L (high impact)	7	6.9 (2 to 12)
>5 mg/L (above CCC guideline)	3	8.7 (1 to 13)

Table 4. Common uses and abbreviations for chemicals found in Cape Cod private wells.

Chemical	Abbreviation	What is it used for?
Pharmaceuticals (antibiotics)		
monensin	Mon	Veterinary antibiotic used in feed for cows, goats, and chickens.
sulfachloropyridazine	SulfCP	Veterinary antibiotic commonly used for livestock.
sulfamethoxazole	SulfMX	Antibiotic, commonly used to treat urinary tract infections and pneumonia. Often used in combination with trimethoprim.
sulfathiazole	SulfTZ	Antibiotic, mostly used to treat aquarium infections.
trimethoprim	Trim	Antibiotic, commonly used to treat urinary tract infections and pneumonia. Often used in combination with sulfamethoxazole.
Pharmaceuticals (other than antibiotics)		
antipyrine	Antip	Analgesic for relieving pain of ear infections.
carbamazepine	Carb	Anti-convulsant medications used to treat epilepsy and bipolar disorder.
cotinine	Cot	Breakdown product of nicotine.
gemfibrozil	Gem	Lipid regulator (lowers cholesterol and fatty acids in blood).
meprobamate	Mep	Anti-anxiety medication.
primidone	Prim	Anti-convulsant medication used to control seizures.
simvastatin (Zocor)	Simv	Lipid regulator (lowers cholesterol and fatty acids in blood).

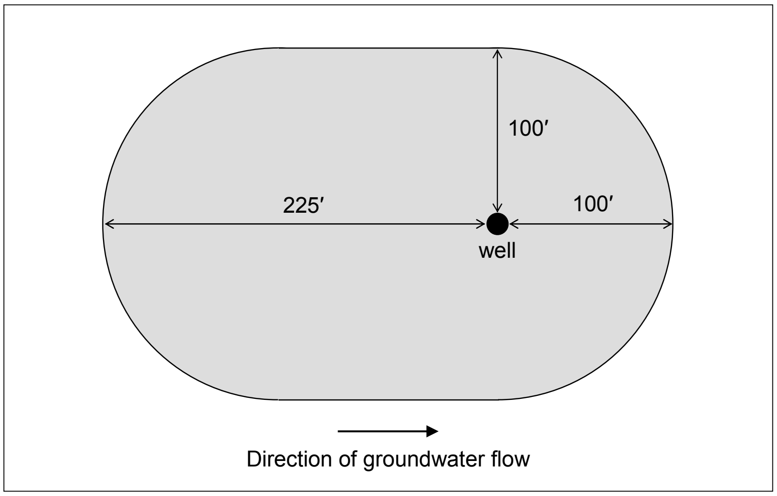
Chemical	Abbreviation	What is it used for?
Perfluorinated chemicals	*Used in non-stick and stain resistant products, or byproducts of manufacturing. Some have been found to cause liver toxicity, changes in hormone and cholesterol levels, and impaired growth and development in laboratory studies.*	
perfluorobutanesulfonic acid	PFBS	Water and stain protective coatings for carpets, paper and textiles, including Scotchgard products.
perfluoroheptanoic acid	PFHpA	Present in stain- and grease-proof coatings on food packaging, furniture, and household products. There is limited publicly available information on specific uses and sources of these chemicals.
perfluorohexanoic acid	PFHxA	
perfluorohexanesulfonic acid	PFHxS	
perfluorooctanesulfonic acid	PFOS	A breakdown product of stain- and grease-proof coatings on food packaging, furniture, and household products. Most chemicals known to break down into PFOS have not been produced or used in consumer products in the US since about 2002. PFOS itself is still produced internationally and imported for a few industrial uses, including firefighting foams and aviation hydraulic fluids.
Organophosphate flame retardants	*Used as flame retardants and plasticizers. Some have been found to cause cancer, neurotoxicity and liver damage in laboratory studies.*	
2-ethylhexyldiphenyl phosphate	2-EHDP	Plasticizer in plastics including PVC, vinyl film for food packaging; fire-resistant fluids.
tributyl phosphate	TBP	Solvent used in exterior paints and herbicides. Industrial uses include aircraft hydraulic fluids, solvents for metal extraction and antifoaming agents.
triethyl phosphate	TEP	Flame retardant and plasticizer used in producing plastics. Industrial uses include production of chemicals, including pesticides.
triphenyl phosphate	TPP	Flame retardant used in making electrical and automobile components and in upholstery; plasticizer; component of hydraulic fluids and lubricant oils.

Chemical	Abbreviation	What is it used for?
Hormones		
cis-testosterone	Test	Natural sex hormone.
progesterone	Prog	Natural sex hormone.
Miscellaneous		
acesulfame	Ace	Common artificial sweetener that does not readily break down. Used in diet sodas and other foods and beverages, and sold under brand names Sunett and Sweet One. Has been previously measured in groundwater as a marker of wastewater impact.
bisphenol A	BPA	Additive to plastics and epoxy resins; found in polycarbonate and some other plastics. May leach in small amounts from some plastic water pipes or pump fittings. Most exposure comes from food packaging, especially canned foods and baby bottles. Exposure to BPA has been associated with effects on the developing brain, and mammary and prostate glands in laboratory studies.
DEET (N,N-diethyl-meta-toluamide)	DEET	Insect repellent. Approved by EPA for application directly to skin; limited evidence of toxicity.
salicylic acid	Sal	Anti-acne and other skin treatments.

Sources:

3M Company, http://solutions.3m.com/wps/portal/3M/en_US/PFOS/PFOA/Information/phase-out-technologies/
Canadian National Collaborating Centre for Environmental Health, http://www.ncceh.ca/sites/default/files/Health_effects_PFCs_Oct_2010.pdf
Drug Information Online, http://www.drugs.com
Environmental Working Group, http://www.ewg.org/chemindex/
International Program on Chemical Safety, http://www.inchem.org
National Toxicology Program, http://ntpsearch.niehs.nih.gov/index.html?col=010stat
Scorecard – The Pollution Information Site, http://scorecard.goodguide.com
Toxnet Toxicology Data Network, Hazardous Substances Database, http://toxnet.nlm.nih.gov/cgi-bin/sis/search
US EPA High Production Volume Information System, http://www.epa.gov/hpv/hpvis/index.html
World Health Organization, https://apps.who.int/dsa/cat97/zehc2.htm

Figure 1. (a) Sample recharge area used to estimate extent of residential development in area influencing each private well. This approach is based on the methodology of Kerfoot and Horsley[14] and is designed to include the predominantly upgradient direction of the recharge area and to incorporate potential seasonal fluctuations in the direction of flow.



(b) Examples of possible well recharge areas for two private wells. Recharge areas represent the area of land that contributes water to a certain well. Depending on the direction of groundwater flow and well depth, recharge areas can be at different distances away from the well. Note that the distance between the recharge area and the well can vary considerably based on the predominant direction of groundwater flow. Adapted from Fig. 3 in Horsley & Witten Inc., 2000.[31]

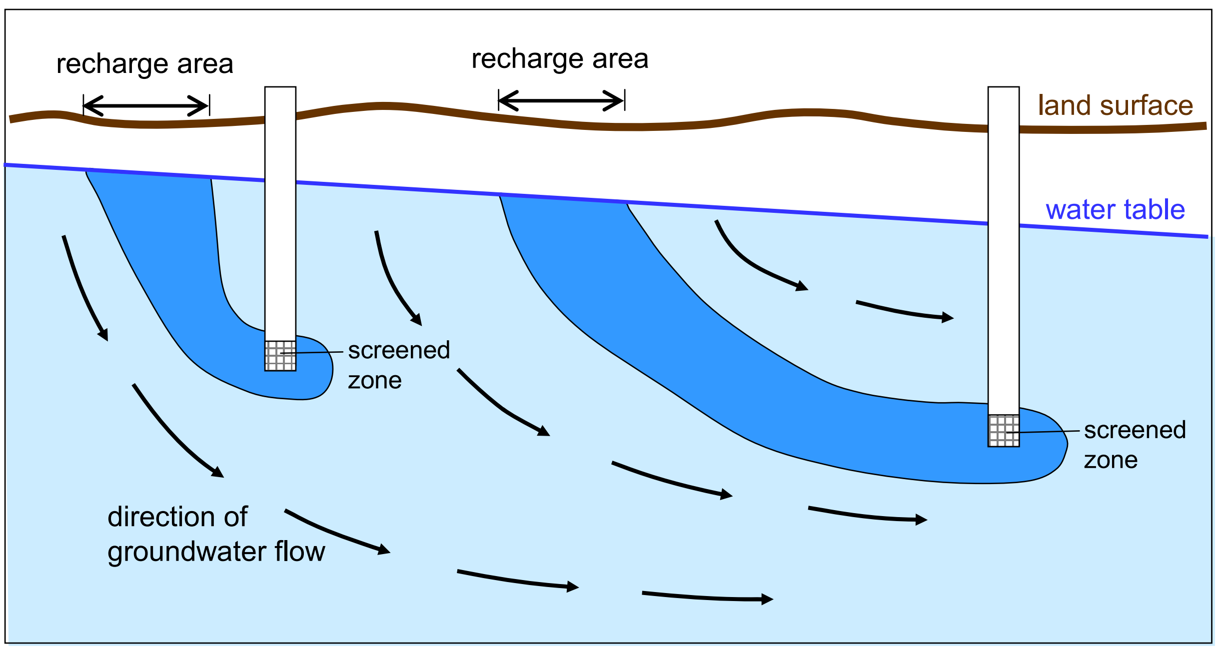


Figure 2. Number of wells (out of 20) containing various classes of emerging contaminants. The numbers in parentheses indicate how many chemicals were found and how many were tested within each category.

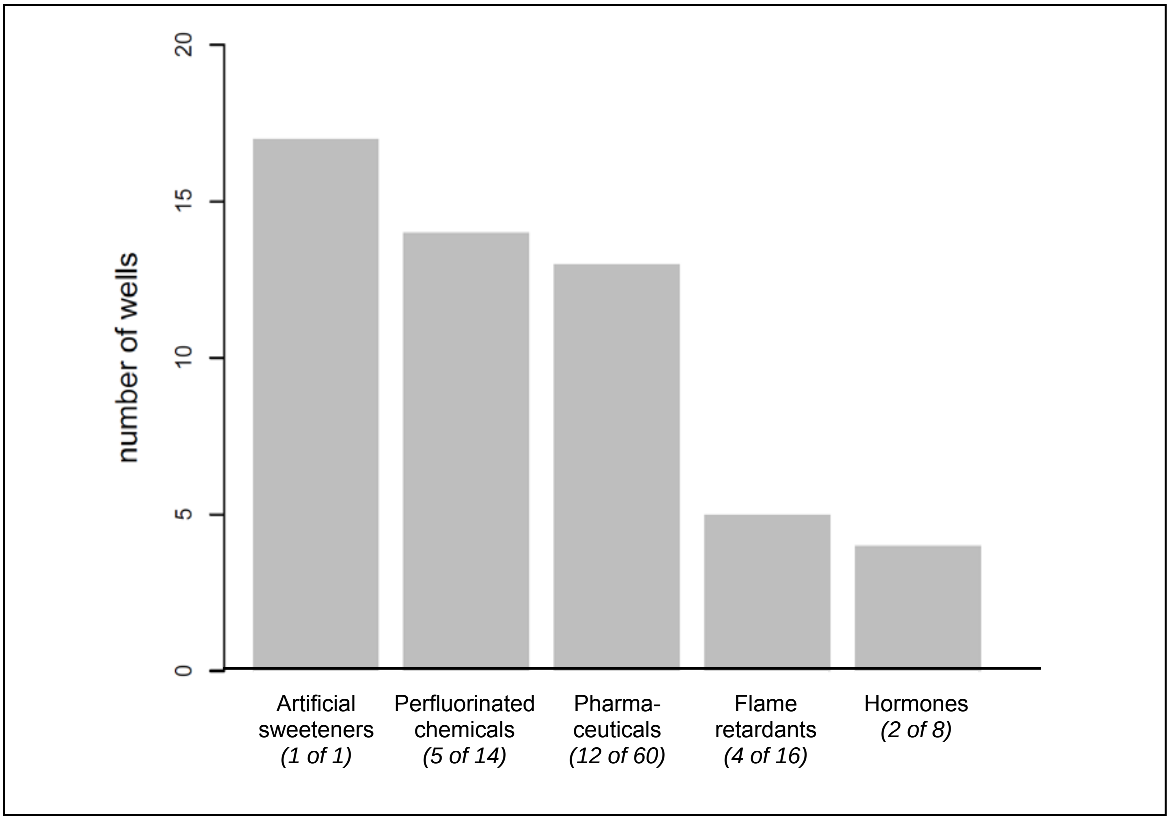
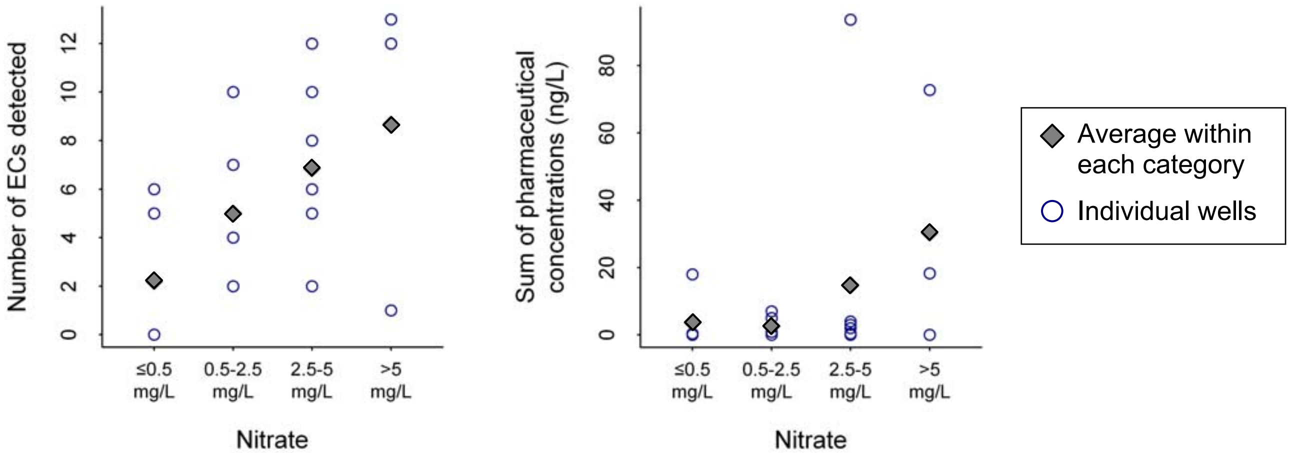
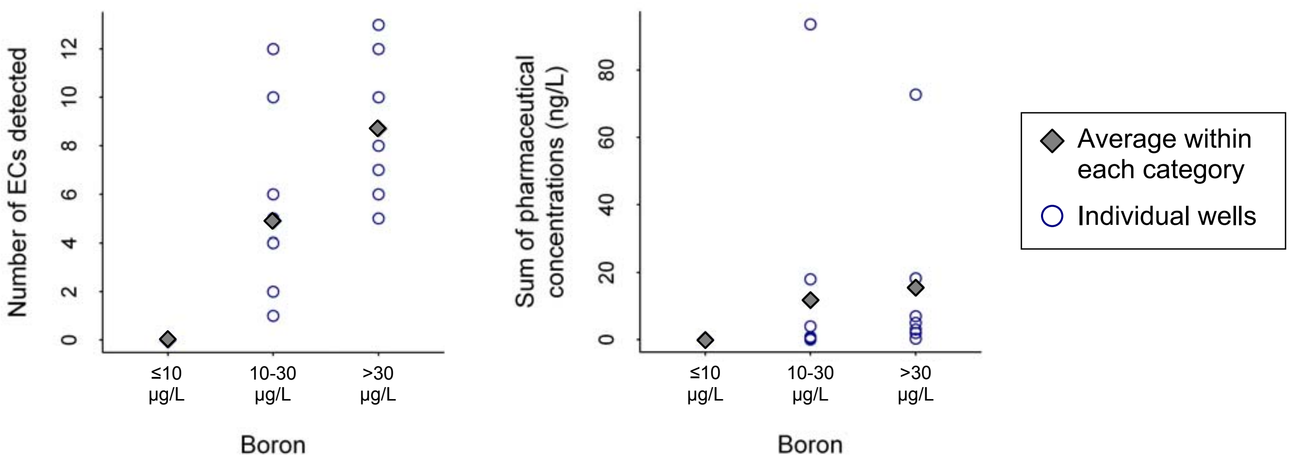


Figure 3. Number of emerging contaminants (ECs) detected and total pharmaceutical concentrations detected (in nanograms per liter) in private well samples, according to concentrations of (a) nitrate, (b) boron and (c) average residential density.

(a) Nitrate categories: minimally impacted (≤0.5 mg/L), moderately impacted (0.5-2.5 mg/L), highly impacted (2.5-5 mg/L) and above the Cape Cod Commission's guideline value (>5 mg/L). Nitrate is present in domestic wastewater and can also come from fertilizers.



(b) Boron is present in detergents and soaps, and elevated boron concentrations in groundwater can also result from saltwater intrusion.



(c) Average residential density (households per acre) in well recharge areas.

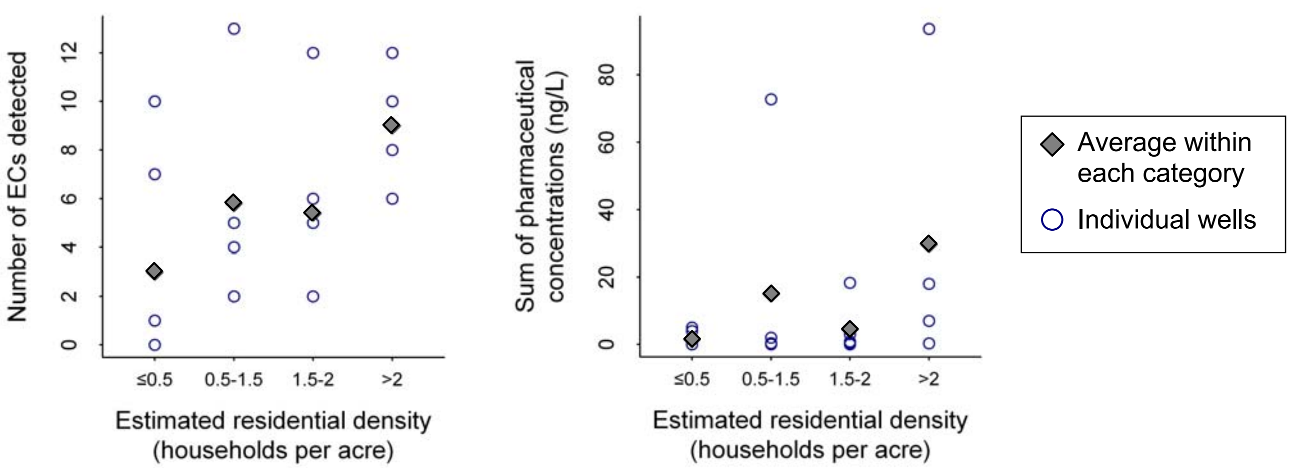
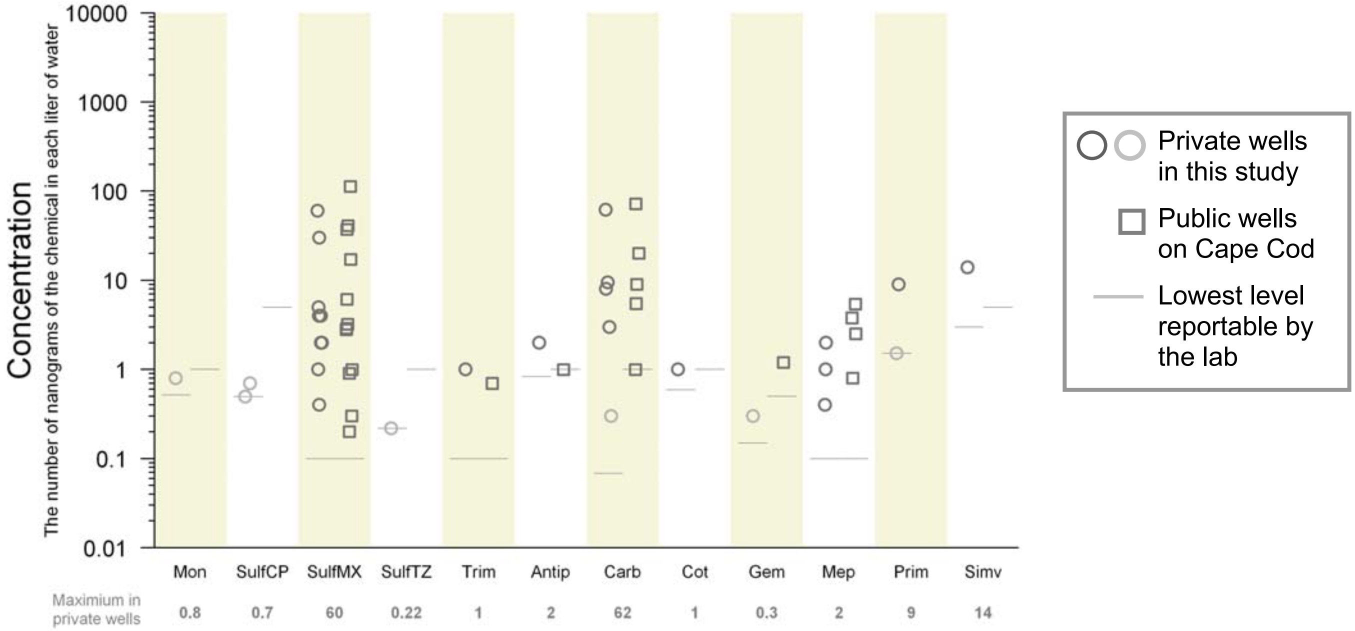
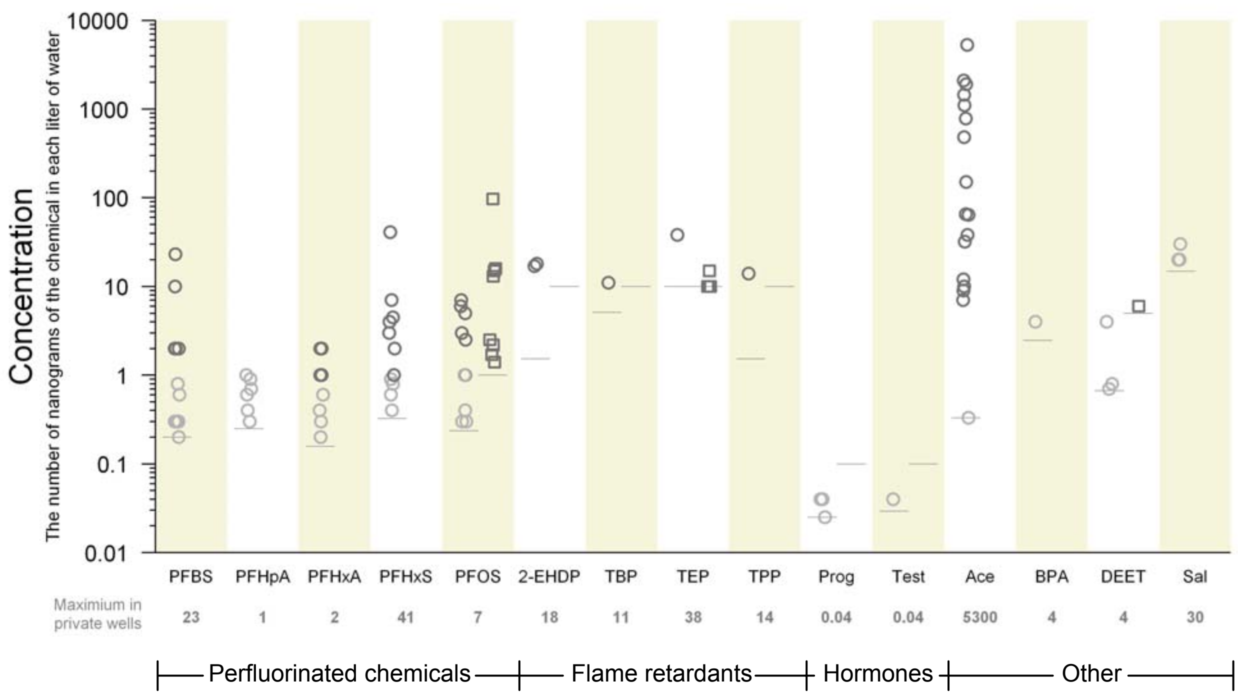


Figure 4. Concentrations of emerging contaminants in individual private wells in this study and in Silent Spring Institute's 2010 study of public wells. Abbreviations in Table 4.

(a) Pharmaceuticals



(b) Perfluorinated chemicals, organophosphate flame retardants, hormones, and other emerging contaminants.



Appendix 1. Complete list of emerging contaminants tested in this study. Chemicals in **bold** were found at least once.

DL = laboratory detection limit (lowest level quantified by the laboratory)
ng/L = nanograms per liter (parts per trillion)

Pharmaceuticals: antibiotics	DL (ng/L)
azithromycin	4.4
bacitracin	280
carbadox	1.1
chloramphenicol	1.1
chlorotetracycline	28
ciprofloxacin	18
doxycycline	24
enrofloxacin	32
erythromycin	0.86
lasalocid	0.52
lincomycin	0.03
monensin	0.52
narasin	0.16
norfloxacin	24
oleandomycin	0.13
oxytetracycline	260
penicillin g	0.53
penicillin v	0.43
roxithromycin	0.15
salinomycin	0.013
sulfachloropyridazine	0.58
sulfadiazine	0.29
sulfadimethoxine	0.029
sulfamerazine	0.32
sulfamethazine	0.17
sulfamethizole	0.43
sulfamethoxazole	0.1
sulfasalazine	1.1
sulfathiazole	0.27
tetracycline	220
trimethoprim	0.1
tylosin	0.35
virginiamycin	0.65

Pharmaceuticals: prescription	DL (ng/L)
antipyrine	0.83
atenolol	0.1
bezafibrate	0.099
carbamazepine	0.068
clofibric acid	0.059
dexamethasone	2
diazepam	0.34
diclofenac	0.16
diltiazem	0.034
fluoxetine (Proxac)	0.31
gemfibrozil	0.15
iopromide	14
levothyroxine (Synthroid)	0.66
meprobamate	0.1
naproxen	0.41
phenytoin (Dilantin)	0.78
prednisone	0.54
primidone	2.1
simvastatin	3
theophylline	1.6

Pharmaceuticals: non-prescription	DL (ng/L)
acetaminophen	2.3
caffeine	10
cotinine	0.59
ibuprofen	1.9
nicotine	2.5
paraxanthine	2.4
theobromine	14

Perfluorinated chemicals	DL (ng/L)
n-ethyl perfluorooctanesulfonamido-acetic acid (NEtFOSAA)	1
n-methyl perfluorooctanesulfon amido-acetic acid (NMeFOSAA)	1.3
perfluorobutanesulfonic acid (PFBS)	0.22
perfluorodecanoic acid (PFDA)	0.28
perfluorododecanoic acid (PFDoA)	0.23
perfluoroheptanoic acid (PFHpA)	0.25
perfluorohexanesulfonic acid (PFHxS)	0.33
perfluorohexanoic acid (PFHxA)	0.16
perfluorononanoic acid (PFNA)	0.45
perfluorooctanesulfonic acid (PFOS)	0.24
perfluorooctanoic acid (PFOA)	0.57
perfluorotetradecanoic acid (PFTA)	0.93
perfluorotridecanoic acid (PFTrDA)	0.55
perfluoroundecanoic acid (PFUnA)	0.29

Hormones	DL (ng/L)
17α-estradiol	0.21
17α-ethinylestradiol	0.23
17β-estradiol	0.28
cis-testosterone	0.029
diethylstilbestrol (DES)	0.24
estriol	0.31
estrone	0.16
progesterone	0.028
trans-testosterone	0.032

Alkylphenols	DL (ng/L)
4-nonylphenol diethoxylate (NP2EO)	24
4-nonylphenol ethoxycarboxylate (NP1EC)	11
4-nonylphenol monoethoxylate (NP1EO)	92
4-nonylphenol phenoxyethoxy-carboxylate (NP2EC)	15
4-nonylphenol triethoxylate (NP3EO)	57
4-n-octylphenol	15
4-t-octylphenol	27
nonylphenol	18

Organophosphate flame retardants	DL (ng/L)
2-ethylhexyldiphenyl phosphate	1.5
diphenylcresyl phosphate	1.5
tributyl phosphate	5.1
triethyl phosphate	10
tri-m-cresyl phosphate	1.5
trimethyl phosphate	10
tri-o-cresyl phosphate	1.8
tri-p-cresyl phosphate	1.2
tripentyl phosphate	2.2
triphenyl phosphate	1.5
tris(1,3-dichloro-2-propyl) phosphate	1.2
tris(2,3-dibromopropyl) phosphate	53
tris(2-butoxyethyl) phosphate	39
tris(2-chloroethyl) phosphate	1.7
tris(2-ethylhexyl) phosphate	1.8
tris(chloropropyl) phosphate	8.4

Herbicides	DL (ng/L)
2,4-D	1.4
dicamba	13
dichlorprop	1.7
fosamine	2100
glyphosate	1400
imazapyr	260
MCPA	1.5
triclopyr	1.6

Miscellaneous chemicals	DL (ng/L)
acesulfame	0.42
bisphenol A (BPA)	2.5
DEET	0.67
salicylic acid	15
triclocarban	0.73
triclosan	3

Appendix 2. Summary of quality assurance/quality control (QA/QC) samples

Blanks: Two field blanks were collected over the course of our sampling and analyzed for every chemical of interest, except mercury. Field blanks were collected by pouring analytical-grade water that supplied by the laboratory into sampling bottles at two of the field sites. When analyzing our samples, the laboratory did not know which samples were field blanks. Underwriters Laboratory (which performed all of the analyses except for total nitrogen, total organic carbon, and mercury) also reported to us results for blank samples prepared in the laboratory. Woods Hole Oceanographic Institution, which performed the mercury analyses, provided data adjusted for the level of mercury detected in laboratory blanks.

Of the 127 chemicals tested for (121 emerging contaminants + nitrate, boron, mercury, sodium, total organic carbon, total nitrogen), only mercury and 5 emerging contaminants were detected in any blanks. Only one of the emerging contaminants that we detected in blanks, the perfluorinated chemical PFOA, was also detected in field samples. Because PFOA was detected in all field and laboratory blanks, and because it was found at very low levels in both samples and blanks (3-7 ng/L in samples, 3-4 ng/L in blanks), we have not included PFOA as one of the detected chemicals in this report.

Duplicates: Two samples were collected in duplicate over the course of our sampling. Duplicate samples were collected at the same location into separate collection bottles. When analyzing our samples, the laboratory did not know which samples were duplicates.

In general, the results of the duplicate analyses showed very good reproducibility (see Table A2.1).

Table A2.1. Percent difference between duplicate analyses. Two well water samples were collected in duplicate (4 for mercury analyses). The percent difference is determined as the difference between the two values divided by the average of the two values. See Table 1 for full chemical names. Duplicate data are only shown for chemicals that were detected in at least one duplicate sample.

-- not detected in either duplicate
** percent difference could not be calculated because one duplicate was above the detection limit and the other was below the detection limit

	SulfCP	SulfMX	SulfTZ	Trim	Carb	Prim	PFBS	PFHpA	PFHxS	PFHxA	PFOS	Prog	Ace
Sample 1	--	--	--	--	--	--	--	--	--	--	--	--	**
Sample 2	**	0%	**	0%	11%	**	0%	0%	22%	0%	40%	40%	7%

	Boron	Nitrate	Sodium	TN
Sample 1	10%	0%	7%	0%
Sample 2	3%	0%	0%	1%

	Mercury
Sample 1	19%
Sample 2	21%
Sample 3	10%
Sample 4	100%