

Onsite Sewage Treatment and Disposal Systems: Trace Organic Chemicals¹

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*This publication is part of a series titled **Onsite Sewage Treatment and Disposal Systems**, commonly referred to as septic systems. This series is intended to give state and local government officials, soil scientists, consulting engineers, Extension agents, and citizens a basic understanding of onsite wastewater treatment and the behavior of different wastewater-borne contaminants coming from septic systems.*

Introduction and Purpose

Onsite sewage treatment and disposal systems (hereafter referred to as septic systems) are commonly designed to prevent groundwater contamination from conventional wastewater pollutants such as total suspended solids, nitrogen, phosphorus, and pathogens. However, contamination concerns associated with trace organic chemicals found in septic systems may present environmental or human health problems. Trace organic chemicals are sometimes referred to as “emerging contaminants,” “contaminants of emerging concern,” “micro-constituents,” or “trace organic compounds.” To simplify, these compounds will be referred to as **trace organic chemicals** in this publication. Trace organic chemicals are potentially harmful to human and ecosystem health. They frequently occur in wastewater from septic systems and can be found in concentrations orders of magnitude higher than typical concentrations reported in centralized treatment plant wastewater (Conn et al. 2006; Godfrey et al. 2007).

The objective of this publication is to characterize the sources and behavior of trace organic chemicals in septic systems. Specifically, this publication (1) identifies common trace organic chemicals of concern in wastewater and their sources, and (2) summarizes current research on the fate and transport of these chemicals in septic systems. For an overview of septic systems, consult *Onsite Sewage Treatment and Disposal Systems: An Overview* by Toor et al. (2011) available at <http://edis.ifas.ufl.edu/ss549>.

Trace Organic Chemicals in Domestic Wastewater

Domestic wastewater is a complex mixture of various contaminants. Wastewater may contain numerous trace organic chemicals at a wide range of concentrations depending on social factors such as household activity, number, and age, as well as the health status of residents, water use practices, and geographic location. Possible trace organic chemicals of concern in domestic wastewater are categorized as follows:

- **Consumer product chemicals:** Examples include surfactants (present in dishwashing liquids and soaps), caffeine, and antimicrobial chemicals such as triclosan (commonly found in soap).
- **Pharmaceuticals:** These include drugs, drug byproducts, and hormones ingested for pharmaceutical purposes

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and passed through the human body or disposed of by flushing down the toilet.

- **Pesticides:** Examples include DEET, a common insect repellent, and commercially available mixtures washed off the body or household surfaces in the bath or shower.
- **Volatile organic compounds:** These include flame retardants added to consumer products, solvents, and some cleaning products disposed of by pouring down the drain.

Data describing trace organic chemical concentrations in wastewater from septic systems are limited. Studies by Conn et al. (2010) and Lowe et al. (2009) have investigated trace organic chemicals in raw sewage. Quite a few additional studies have investigated the concentrations of these chemicals in septic tank effluent (Conn et al. 2009; Matamoros 2009; Carrara et al. 2008; Sauer and Tyler 1995; Sherman and Anderson 1991). Tables 1 and 2 summarize some organic chemicals commonly found in wastewater or septic tank effluent.

The Fate of Trace Organic Chemicals in Septic Systems

Trace organic chemicals present in septic systems can be removed by the following three mechanisms:

- **Biotransformation:** It is the conversion of trace organic chemicals to other chemicals, which may be in toxic or non-toxic forms, and the eventual conversion to their inorganic building blocks. Biotransformation is chemical-specific and can occur in aerobic or anaerobic conditions.
- **Sorption:** It is the fixation of chemicals on solids, such as the settled sludge in a septic tank or the soil in a drain field or soil treatment unit.
- **Volatilization:** It is the conversion of trace organic chemicals from the dissolved form in water to gaseous forms that are released into the air.

The degree to which these removal mechanisms work varies widely because there are numerous trace organic chemicals that may be present in wastewater and these substances each have unique chemical properties. The brief literature review below summarizes a few of the most recent findings on the behavior of trace organic chemicals in septic systems. The important message here is that removal of trace organic chemicals is chemical- and site-specific. Therefore, it is difficult to make broad assertions about how trace organic chemicals are removed or transported in the soil environment.

Biotransformation

Biotransformation may take place in the septic tank or in the drain field. In this process, parent compounds

Table 1. Summary of consumer product chemical concentrations in raw wastewater and septic tank effluent.

Chemical	Use	Raw Wastewater, µg/L	Septic Tank Effluent, µg/L
Caffeine	stimulant	7.1 – 1800	1.6 – 850
EDTA	metal-chelating agent	6.3 – 720	3.8 – 100
4-nonylphenol	surfactant metabolite	< 2 – 66	< 2 – 650
NP1EO	surfactant metabolite	3.5 – 1000	3.5 – 1000
Triclosan	antimicrobial	0.4 – 240	0.9 – 55

Source: Lowe et al. (2009).

Table 2. Common pharmaceutical chemicals, pesticides, and other trace organic contaminants found in domestic wastewater.

Chemical	Use	Frequency of Detection in Septic Tank Effluent ^a (%)	Frequency of Detection in Receiving Water Bodies ^a (%)
Diclofenac	anti-inflammatory	5/16 (31)	0/4 (0)
Ibuprofen	anti-inflammatory	14/16 (88)	1/4 (25)
Ketoprofen	analgesic	2/16 (13)	0/4 (0)
Naproxen	analgesic	10/16 (63)	0/4 (0)
Salicylic acid	anti-inflammatory	16/16 (100)	4/4 (100)
Caffeine	stimulant	16/16 (100)	3/4 (75)

^aTaken from Matamoros et al. (2009). NR: not reported.

are broken down into simpler substances often called metabolites.

Metabolites may or may not be more environmentally acceptable (less toxic) than their parent compounds. It is important to note that degradation does not necessarily equate to detoxification. Celiz et al. (2010) provide a review of recent studies on pharmaceutical metabolites. They point out that byproducts of biotransformation can often be just as toxic as the chemicals from which they are derived. Therefore, it is important to consider chemical metabolites rather than making influent/effluent comparisons of the parent compound alone.

Topp et al. (2006) and Shimp et al. (1994) checked for the presence of caffeine and nitrilotriacetic acid (a consumer product chemical) under septic systems. They found that both were reduced to less than measurable levels within the first 2 feet of soil. They attributed this reduction to microbial transformations, but no information on potential metabolites was provided. In contrast, the trace organic chemical ethylenediaminetetraacetic acid (EDTA) has been found to persist while being transported through the soil. This observation is attributed to EDTA's resistance to biotransformation unless certain environmental conditions are met, as described below (Conn et al. 2010; Yoo et al. 2006).

Biotransformation of several trace organic chemicals depends on pH. For example, EDTA forms strong chemical complexes with iron at neutral to acidic pH values. (A **chemical complex** is a structure that consists of a central metal atom bonded to a surrounding array of other molecules). Microorganisms capable of degrading EDTA can only transfer it through their bacterial cell membranes when the EDTA is complexed with calcium or magnesium, not iron. Thus, EDTA is more likely biodegraded when pH values are greater than 8.0 (Conn et al. 2010).

The degree to which other chemicals biodegrade depends on their chemical structure. For example, ketoprofen and diclofenac have been shown to be highly resistant to biodegradation because of specific structural characteristics that impede microbial breakdown (Kimura et al. 2005). Patterson et al. (2010) added that the time required for biodegradation varies among organic chemicals. After studying nine consumer product and pharmaceutical chemicals, Patterson et al. (2010) observed a range in biodegradation time from 1 to more than 100 days.

Sorption

Trace organic chemicals may also adsorb or sorb to soil surfaces, especially those associated with soil organic matter. Conn et al. (2010) observed that triclosan (an antimicrobial common in hand sanitizers and soaps) was reduced to less than 0.2 microgram per liter within 2 feet of soil transport. They attributed the reduction to both sorption and biotransformation. The same authors also observed removal of the pharmaceutical compound sulfamethoxazole by soil sorption. Conkle et al. (2010) found that soil sorption was a significant removal pathway for pharmaceuticals and observed 60%–90% removal of various pharmaceuticals by a wetland soil receiving effluent. These authors added that the organic chemicals in their study were found to compete for soil sorption sites.

Some advanced septic system designs incorporate a passage along or through solid material into the treatment system. An example is a textile biofilter, which the septic tank effluent passes through before it is discharged into the drain field. A biofilter can increase opportunities for adsorption of organic contaminants (Dordio et al. 2007). However, other researchers have observed that biofilters work no better than natural soils as long as the soils are unsaturated (Matamoros et al. 2009; Conn et al. 2010).

Ruffino and Zanetti (2009) pointed out that the adsorption capacity for any organic chemical is believed to depend upon three main factors:

1. Sorbate (the substance that adsorbs the chemical) characteristics like polarity, hydrophobicity, molecular size, aqueous solubility, functional groups present, and branching.
2. Characteristics of the liquid phase like pH, temperature, and ionic strength.
3. Sorbent (the chemical being adsorbed) characteristics like surface area, organic matter, mineral surfaces, and pore size.

For example, hydrophilic (easily dissolved in water) compounds are generally found to resist removal by sorption (Matamoros et al. 2009). Organic chemicals that contain chlorine in their structure will exhibit greater electro-negativity (more negative charges) and will be better able to interact with any positive-charged sites on soil surfaces (Ruffino and Zanetti 2009), resulting in strong adsorption.

Volatilization

Volatilization is the gaseous loss of a substance to the atmosphere. This process may occur in the septic tank or in the soil drain field. Not all volatile organic compounds will be completely volatilized. Some fractions may also biodegrade or be sorbed, while others may simply leach to groundwater in non-degraded form. However, for organic compounds that can undergo volatilization, the process can be a significant means of contaminant removal, even if it does not result in *complete* removal (Yates 2009). Sherman and Anderson (1991) analyzed volatile organic compounds (VOCs) in septic tank effluent samples from eight homes in Florida during a 6-month period. They routinely found VOCs in the septic tank effluent. Toluene was found in every septic tank sampled and in almost every wastewater sample analyzed. However, soil cores taken at numerous locations below the drain fields of these homes did not show VOC concentrations above detection limits except in one soil sample from directly below the septic tank outlet.

The most important factor that determines the degree of volatilization is the contaminant's vapor pressure, which is a measure of how quickly a chemical liquid will evaporate. The contaminant's vapor pressure is unique to each organic chemical and relative to its solubility in water. Other factors that influence volatilization are the following:

- Temperature: Higher temperatures encourage greater volatilization.
- Soil moisture content: Higher soil moisture content reduces air-filled pore space, which reduces volatilization.
- Soil texture: Coarser textures allow more movement of chemicals through the soil profile and more interaction with air-filled pore spaces, which increases volatilization.

Trace Organic Chemicals and Water Quality

Ongoing research is studying the effects of trace organic chemicals in drinking water and aquatic environments. Several researchers have established a connection between endocrine disrupting compounds (hormones and hormone mimics in consumer product chemicals) and adverse effects on aquatic organisms in surface waters that receive effluents containing trace organic chemicals (Milnes et al. 2006; Blazer et al. 2007; Vajda et al. 2008). One such adverse effect is the development of intersex fish with both male and female reproductive tissue. Underwood et al. (2011) assert that increased antibiotic concentrations in the soil

environment will have adverse effects on the soil microbial community and will alter the ability of certain bacteria to carry out ecosystem services such as nutrient cycling and waste degradation.

Hinkle et al. (2009) studied 63 trace organic chemicals from septic tank effluent in a shallow sandy aquifer and found 45 of them in at least 90% of effluent samples from septic tanks, indicating their widespread use and the limited treatment effectiveness of the septic tank. They found only nine trace chemicals (caffeine, plus eight pharmaceuticals) in groundwater samples taken from adjacent areas (no more than 19 feet away). Pharmaceutical concentrations in the groundwater were up to 120 micrograms per liter but were as high as 1,300 micrograms per liter in effluent; this indicates that significant removal through a combination of sorption and volatilization did occur in the drain field, the soil below, and the groundwater.

Nielsen et al. (2002) investigated the fate and transport of several surfactants from a Florida septic system sited in fine sandy soil with a shallow water table. Three trace organic chemicals — linear alkylbenzene sulfonate (LAS), alcohol ethoxylate (AE), and alcohol ether sulfate (AES) — were monitored in septic tank effluent, soil, and groundwater during wet season and dry season sampling events. These compounds were consistently present in the septic tank effluent. While AE was not detected in any groundwater samples and AES was not found in the dry season, trace quantities had migrated down gradient in the wet season. LAS was detected in some dry season samples, and it also migrated down gradient in the wet season. AES and LAS were found only in very low concentrations in groundwater, and their transport down gradient was significantly less than a conservative tracer (bromide). The most likely removal mechanisms for these three surfactants were biodegradation and sorption.

Godfrey et al. (2007) detected 18 of 22 pharmaceuticals studied in septic tank effluent, and Swartz et al. (2006) observed transport of caffeine, estrogens, and other trace organic chemicals in groundwater up to 20 feet down gradient of drain fields. Carrara et al. (2007) compared organic chemical concentrations in septic tank effluent with concentrations in groundwater. They found 10 of 12 chemicals analyzed in groundwater at concentrations in the low nanogram per liter to low microgram per liter range. Ibuprofen and naproxen were transported in the highest concentration and to the greatest distance.

Standley et al. (2008) explored the extent to which groundwater contaminated by discharge from septic

systems affected water quality in surface water ecosystems. They measured steroidal hormones, pharmaceuticals, and other organic chemicals in groundwater collected from six aquifer-fed ponds in areas of higher and lower residential density in Cape Cod, Massachusetts. They detected a greater number and higher concentrations of trace organic chemicals in samples collected from ponds located in higher-density residential areas. The chemicals most frequently detected were the steroidal hormones androstenedione, estrone, and progesterone, and the pharmaceuticals carbamazepine, pentoxifylline, sulfamethoxazole, and trimethoprim. A particular concern in this study was that estrogenic hormones were present at concentrations approaching those found to induce physiological responses in fish.

According to Conn et al. (2006), concentrations of 4-nonylphenol (a surfactant metabolite) as low as 10 micrograms per liter can disrupt endocrine function in aquatic organisms. The U.S. Environmental Protection Agency has established a toxicity-based water quality criteria for 4-nonylphenol with a 4-day average concentration in freshwater systems not to exceed 6.6 micrograms per liter. Concentrations of 4-nonylphenol reached 130 micrograms per liter in some of the confined treatment unit effluents assessed by Conn et al. (2006), which required greater than 95% removal prior to recharging the aquatic environment to ensure aquatic health. These authors added that treatment of trace organic chemicals in the soil before groundwater recharge is not well understood and warrants further study. They also point out that once organic chemicals reach the unsaturated soil zone, they may stay there for decades.

Matamoros et al. (2009) provide a good review of numerous pharmaceutical and consumer product chemicals in septic tank effluent and adjacent receiving waters. In their study, caffeine and ibuprofen were especially persistent and were found in nearly 100% of effluent samples and more than 75% of receiving water bodies.

Summary

Trace organic chemicals enter wastewater from human wastes and domestic activities. These compounds vary greatly, and include pharmaceuticals, pesticides, consumer product chemicals, and volatile organic compounds. These chemicals are potentially harmful to ecosystem health, and their effects as well as their fate and transport are an area of active research. These chemicals may be removed from wastewater to some extent in the septic tank or the drain field by biotransformation, sorption, or volatilization. However, the degree to which these processes work is

highly variable, depends on a number of factors, and at this time is difficult to quantify. Numerous organic chemicals have been detected in groundwater and surface waters adjacent to septic systems, providing evidence that at least some trace organic chemicals are not completely removed by these processes. While organic chemicals are usually found only in nanogram per liter to low microgram per liter concentration ranges, their effects on the environment may still be detrimental. Research is ongoing to determine how to best deal with them.

Consult the following EDIS articles in this series for more information on these topics:

[SS549/SL347 - Onsite Sewage Treatment and Disposal Systems: An Overview](#)

[SS550/SL348 - Onsite Sewage Treatment and Disposal Systems: Nitrogen](#)

[SS551/SL349 - Onsite Sewage Treatment and Disposal Systems: Phosphorus](#)

[SS552/SL351 - Onsite Sewage Treatment and Disposal Systems: Bacteria and Protozoa](#)

[SS553/SL352 - Onsite Sewage Treatment and Disposal Systems: Viruses](#)

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