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Detection of pharmaceuticals and other personal care products in groundwater beneath and adjacent to onsite wastewater treatment systems in a coastal plain shallow aquifer

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ABSTRACT

Onsite wastewater treatment systems (OWTS) are the predominant disposal method for human waste in areas without municipal sewage treatment alternatives. Relatively few studies have addressed the release of pharmaceuticals and personal care products (PPCPs) from OWTS to groundwater. PPCP fate and transport from OWTS are important, particularly where these systems are adjacent to sensitive aquatic ecosystems such as coastal areas or wetlands. The objectives of this study were to identify PPCPs in residential wastewater and groundwater beneath OWTS and to characterize the environmental conditions affecting the OWTS discharge of PPCPs to nearby streams. The study sites are in coastal plain aquifers, which may be considered vulnerable "end-members" for subsurface PPCP transport. The PPCPs most commonly detected in the OWTS, at concentrations ranging from 0.12 μg L^{-1} to 12.04 μg L^{-1} in the groundwater, included: caffeine, ibuprofen, DEET, and homosalate. Their presence was related to particulate and dissolved organic carbon abundance.

1. Introduction

Pharmaceuticals and personal care products (PPCPs) represent a variety of chemicals, widely used by consumers on a daily basis, which are often defined by environmental scientists on the basis of their chemical classes and type of usage (Daughton and Ternes, 1999). These PPCPs, which include prescription and non-prescription drugs, cosmetics, cleansers, detergents, and fragrance products, have been detected in water resources globally at ng to μg L^{-1} concentrations (Kolpin et al., 2002; Barnes et al., 2008; Focazio et al., 2008; Walraven and Laane, 2009; Loos et al., 2010; Kuroda et al., 2011). An understanding of the fate of PPCPs in aquatic ecosystems and their effects on aquatic organisms is still emerging. Because they are generally not regulated, there is concern that ambient exposure to these chemicals could pose significant ecological and public health threats, especially to more vulnerable sub-populations such as children.

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1.1. Onsite wastewater treatment systems as a source of PPCPs

Possible sources of PPCPs to the environment include human and animal wastes, landfill leachate, biosolid application, and direct disposal of PPCPs into the waste stream (Conn et al., 2006). In rural areas, onsite wastewater treatment systems (OWTS), commonly known as septic systems, are the most common method of wastewater treatment. Most OWTS have three basic components including a septic tank, drain field trenches, and soil. Much of the physical, chemical, and biological treatment of wastewater effluent occurs in the soil beneath the drain field trenches. During subsurface migration, PPCPs have the potential to adsorb or absorb to organic matter and/or undergo transformation and degradation by microbial processes (Lapworth et al., 2012).

Presently, there are very few studies addressing the fate and transport of PPCPs from OWTS in coastal environments. Typically higher concentrations of PPCPs have been found within the septic tank and in suboxic to anoxic portions of the wastewater plume (Swartz et al., 2006). In some cases, vadose zone processes have been found to be effective in reducing concentrations, and/or removing PPCPs from sewage effluent (Godfrey et al., 2007; Carrara et al., 2008; Standley et al., 2008; Conn et al., 2006, 2010a,b; Dougherty et al., 2010). Despite these studies, the loading of PPCPs from OWTS to adjacent water bodies and an understanding of the parameters that affect their attenuation by OWTS

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drainage fields, have not yet been adequately addressed in the literature. Thus, the goals of the present study were to 1) determine if PPCPs were detectable in groundwater beneath and in surface water bodies adjacent to OWTS, 2) quantify specific PPCP concentrations and determine the potential flux into nearby surface waters, and 3) determine how site-specific conditions and ancillary water quality parameters influence PPCP detection and concentrations. Site conditions that were examined included: soil type and separation distance from OWTS to groundwater, and various chemical properties such as pH, dissolved oxygen (DO), electrical conductivity (EC), temperature, total dissolved nitrogen (TDN), dissolved organic carbon (DOC), and specific contaminant properties such as solubility and partitioning behavior. The high density of OWTS utilized near sensitive coastal ecosystems makes the presence of PPCPs a concern for both homeowners and policymakers. The widespread global use of PPCPs and their lack of regulation, coupled with the prevalence of OWTS worldwide suggest that this study may be relevant in other coastal environments globally.

2. Materials and methods

2.1. Study area

The study sites were in a city in the Coastal Plain of North Carolina (NC), with a population of approximately 86,000 people (United States Census Bureau, 2008). Four conventional, gravity-fed, OWTS were studied in the Eastern Pines area of Greenville, NC (Fig. 1). These sites were chosen because they are known to drain into the nutrient sensitive Tar-Pamlico River, which in turn, drains into the Pamlico Sound, the second largest estuary in the United States. Land use in the watershed is mostly residential, with some forested and agricultural areas. Soil survey estimates indicate that the entire watershed has <15% agricultural use, and the contributing upstream area is estimated to have <5% agriculture (http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm). Domestic sewage in the watershed is disposed of entirely by OWTS to the surficial aquifer. The North Carolina Department of Environment and Natural Resources has a monitoring well and sediment core data approximately 1 mile west of the study neighborhood (Eastern Pines Water Association 2 Well; data available at: http://www.ncwater.org/data_and_modeling/Ground_Water_Databases/). The sediment core data from well construction shows that the surficial aquifer is approximately 11 m thick in the area and this aquifer is the main source of groundwater baseflow for low-order streams in the area. The soil survey data was used to determine the dominant soil series in the watershed by using the "area of interest" tool to delineate the boundaries of the watershed, and then using the "soil map" tab to create a spreadsheet with the soil series and percentage cover in 2009. Data including OWTS age, system type, installation date, and tank size were obtained from the OWTS permits filed at the Pitt County Environmental Health Department. Sites were chosen with the goal of having a representative sample of OWTS with variable ages and soil types. System age ranges from 15 to 45 years (created ca. 1970s to the late 1990s — Table S1). Ancillary information about the OWTS and sites may be found in the supplementary section.

Piezometers were installed within the shallow, unconfined surficial aquifer. Deeper aquifer systems, such as those commonly used for drinking water sources, were not included in this study, and no private drinking water wells exist in the area. Groundwater monitoring piezometers (3.18–5.08 cm well diameter; 0.91 m screen interval; PVC pipe) were installed using hand augers at each site. Two of the sites (EP100, EP200) had an intensive piezometer layout (>15) in which piezometers were installed up-gradient, between the drainfield trenches, as well as down-gradient of the system. The less intensive piezometer network (<3) installed at sites EP300 and EP400 only included piezometers up-gradient and between the drainfield trenches. Sites EP100 and EP200 are located on opposite sides of the stream that was sampled in the study. Piezometers adjacent to the drainfield trenches and stream at the intensive sites were nested at different depths (1.23–4.15 m) in an attempt to capture the full vertical extent of the plume and to allow for calculation of vertical hydraulic head gradients that can reveal the vertical components of groundwater flow. Based on preliminary data, a sub-set of piezometers most influenced by the wastewater plume were identified. Due to limited resources, only this sub-set of piezometers was included for PPCP sampling in the present study. Fig. 1 illustrates a typical layout of groundwater monitoring piezometers sampled for PPCPs at one of the four study sites, EP100.

2.2. Environmental readings and sample collection

Groundwater, septic tank, and stream samples were collected from each site in January, May, August, and November 2012. At each piezometer, depth to groundwater was measured using a Solinst 107 TLC meter. After the depth reading, the piezometers were purged, and allowed to recharge. Next, a sample was collected using clean, disposable, plastic,

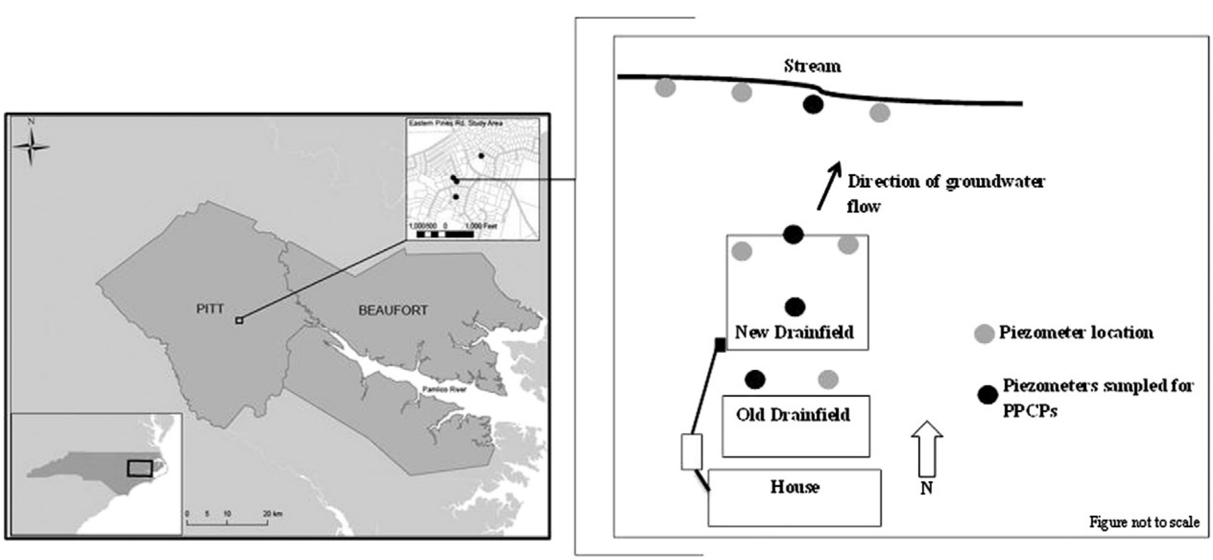

Fig. 1. Geographical location of the four onsite wastewater treatment systems used in this study (left panel) with an expanded map view of one specific study site (EP100) provided in order to illustrate the piezometer network used for groundwater monitoring at the study sites. Other sites were similarly networked with piezometers in an extensive manner.