Soil Persistence and Fate of Carbamazepine, Lincomycin, Caffeine, and Ibuprofen from Wastewater Reuse

C. F. Williams* and J.E.T. McLain

The reuse of treated wastewater for groundwater recharge is an effective way to provide advanced treatment and water storage. Contaminants such as human drugs have been identified as a potential problem for use of this water. Gilbert, Arizona maintains a 28.3-ha facility designed to recharge 15,150 $m^3 d^{-1}$ through recharge basins constructed on native soil. The facility averages an infiltration rate of >5 cm d^{-1}, resulting in the potential of pharmaceutical compounds leaching to groundwater. One 4-ha basin was selected for spatial sampling of four pharmaceutically active compounds (PhACs). The compounds were carbamazepine, lincomycin, ibuprofen, and caffeine. Soils were extracted and analyzed using pressurized liquid extraction and liquid chromatography–mass spectrometry–mass spectrometry. The concentration of ibuprofen was below detection limits in all samples. Lincomycin exhibited no net accumulation from year to year but had significantly higher concentrations from depths of 0 to 5 cm than from depths >10 cm. Carbamazepine had the lowest concentration at 0 to 5 cm (0.18 ng g $soil^{-1}$), providing evidence that there is potential degradation of carbamazepine in surface soils. Carbamazepine also exhibited significant accumulation from year to year. Caffeine exhibited net accumulation and had higher concentrations in surface samples. The accumulation of PhACs in the soil beneath recharge basins indicates that PhACs are being removed from the infiltrating water and that, regarding ibuprofen and lincomycin, the treatment is sustainable due to the lack of accumulation. Regarding carbamazepine and caffeine, further investigations are needed to determine possible management and environmental conditions that could prevent accumulation.

In arid regions, the reuse of wastewater is often seen as a valuable water resource. Treated municipal wastewater can be reclaimed via many mechanisms, including direct reuse (e.g., irrigation or advanced treatment), recharge to groundwater, or release into surface waters for recapture and reuse downstream. Recently, the presence of pharmaceutically active compounds (PhACs) at very low levels in treated effluent has gained the interest of regulators as well as municipal water providers due to increased analytical capabilities and potentially unknown environmental and health effects. The ability to detect and quantify these compounds at environmentally significant concentrations became widely available at the end of the last century (Jorgensen and Halling-Sorensen, 2000). Some of the earliest reports of finding PhACs in the environment occurred in the early 1980s (Halling-Sørensen et al., 1998). More recently, the detection of numerous PhACs in environmental samples has become commonplace (Kolpin et al., 2002; Ternes, 1998, 2001). It is unknown if the presence of these compounds at very low concentrations in environmental samples is biologically relevant.

Understanding the environmental fate of waste water contaminants found in sewage effluent is becoming more important. Many investigations regarding the fate and transport of pharmaceuticals have focused on river and stream systems and hydrologically connected groundwater (Clara et al., 2004; Löffler et al., 2005; Kolpin et al., 2004; Kolpin et al., 2002). Other studies have investigated the fate of pharmaceuticals in terrestrial settings. Kinney et al. (2006) reported that the use of reclaimed waste water for irrigation of turf resulted in the presence of a number of pharmaceutical compounds in the top 30 cm of soil. They also found that the concentration of the individual compounds investigated were <15 μg kg^{-1} in the top 30 cm of soil and that most compounds showed no net accumulation in the soil. This indicates that natural inactivation and removal of the compounds were occurring in the top 30 cm of soil through degradation, sorption, or a combination of both. Williams et al. (2006) reported carbamazepine sorption and desorption coefficients using equilibrium batch techniques for terrestrial

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*Corresponding author (clinton.williams@ars.usda.gov).
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5585 Guilford Rd., Madison, WI 53711 USA

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Abbreviations: HPLC, high-performance liquid chromatography; LC, liquid chomatography; MS, mass spectrometry; OC, organic carbon; PhAC, pharmaceutically active compound; SAT, soil aquifer treatment.