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Perfluorochemicals in water reuse

Megan H. Plumlee [a], Jeannine Larabee [b], Martin Reinhard [a,*]

[a] Department of Civil and Environmental Engineering, Yang & Yamasaki Environment and Energy Building, 473 Via Ortega, Stanford University, Stanford, CA 94305, USA
[b] Santa Clara Valley Water District, 5750 Almaden Expressway, San Jose, CA 95118, USA

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ABSTRACT

Faced with freshwater shortages, water authorities are increasingly utilizing wastewater reclamation to augment supplies. However, concerns over emerging trace contaminants that persist through wastewater treatment need to be addressed to evaluate potential risks. In the present study, perfluorinated surfactant residues were characterized in recycled water from four California wastewater treatment plants that employ tertiary treatment and one that treats primary sewage in a wetland constructed for both treatment and wildlife habitat. Effluent concentrations were compared with surface and groundwater from a creek where recycled water was evaluated as a potential means to augment flow (Upper Silver and Coyote Creeks, San Jose, CA). In the recycled water, 90–470 ng/l perfluorochemicals were detected, predominantly perfluorooctanoate (PFOA; 10–190 ng/l) and perfluorooctanesulfonate (PFOS; 20–190 ng/l). No significant removal of perfluorochemicals was observed in the wetland (total concentration ranged 100–170 ng/l across various treatment stages); in this case, 2-(*N*-ethylperfluorooctanesulfonamido) acetic acid (*N*-EtFOSAA), perfluorodecanesulfonate (PFDS), and PFOS were dominant. Though there is currently no wastewater discharge into the creeks, perfluorochemicals were found in the surface water and underlying groundwater at a total of 20–150 ng/l with PFOS and PFOA again making the largest contribution. With respect to ecotoxicological effects, perfluorochemical release via recycled water into sensitive ecosystems requires evaluation.

1. Introduction

With ecosystems increasingly stressed by the shortage of freshwater, treated wastewater effluent is a promising water resource for the augmentation of water-starved environments. Historically, release of treated wastewater to surface water has been commonplace given the lack of alternatives. Water recycling, however, requires consideration of a complex set of benefits and risks at sites where a natural source (rain, groundwater, rivers) is replaced or augmented with tertiary effluent. Considerations include ecological effects and contamination of potable aquifers with potentially harmful organic contaminants.

Perfluorochemicals represent one such group of contaminants. They are used in a variety of materials such as food packaging, paints, and lubricants (Kissa, 1994) and have been detected in wastewater (Alzaga and Bayona, 2004; Boulanger et al., 2005; Schultz et al., 2006; Sinclair and Kannan, 2006; Loganathan et al., 2007), surface water (Hansen et al., 2002; Moody et al., 2002; Boulanger et al., 2004; Boulanger et al., 2005; Simcik and Dorweiler, 2005; Rostkowski et al., 2006; Sinclair et al., 2006; Skutlarek et al., 2006; McLachlan et al., 2007; So et al., 2007), groundwater (Moody et al., 2003; Schultz et al., 2004), drinking water (Harada et al., 2003; Skutlarek et al., 2006; Paustenbach et al., 2007), and rain (Loewen et al., 2005; Scott et al., 2006). Table 1 summarizes the aquatic occurrence of two commonly detected perfluorochemicals, perfluorooctanoate (PFOA) and perfluorooctanesulfonate (PFOS).

Laboratory studies demonstrate that mammals readily absorb PFOA and PFOS during oral and inhalation exposures. They tend to distribute to the blood serum and the liver and can cross the blood-brain and placental barriers (Lange et al., 2006). Although research shows that PFOA, perfluorononanoate (PFNA), and PFOS are not estrogenic (Maras et al., 2006), high doses of PFOA and PFOS lead to mortality while lower doses result in hepatotoxic, immunotoxic, neurotoxic, and behavioral effects (Lange et al., 2006). When present in a mixture, PFOS may enhance the toxicity of other compounds by increasing cell membrane permeability (Hu et al., 2003; Jernbro et al., 2007). Perfluorochemicals bioaccumulate and have been detected in biota around the world, including fish, seals, minks, albatross, bald eagles, polar bears, and humans (Giesy and Kannan, 2002; Schultz et al., 2003). Typical concentrations of PFOA and PFOS in the serum of non-occupationally exposed humans are 3–35 and 7–82 μg/l, respectively (Hansen et al., 2001; Kannan et al., 2004). These levels are concerning given that adverse effects have been observed in rats at levels (370 μg/l PFOA) which differ from humans by less than a safety factor of 100 (Butenhoff et al., 2004; Lange et al., 2006). Wildlife monitoring studies for high trophic levels report PFOS concentrations of 8–242 μg/l serum in ringed seals (Kannan et al., 2001a), 3–34 μg/l

* Corresponding author. Tel.: +1 650 723 0308; fax: +1 650 723 7058.
E-mail address: reinhard@stanford.edu (M. Reinhard).

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Table 1
Summary of perfluorochemical occurrence in wastewater, freshwater, and drinking water

Site and location	PFOA (ng/l)	PFOS (ng/l)	Other perfluorochemicals detected	Source of perfluorochemicals[a]	References
Wastewater effluent					
2 WWTPs (Catalonia, Spain)	<100–4300	n.m.	PFDA (50-8170)	Domestic and industrial influents	Alzaga and Bayona, 2004
WWTP (Iowa City, Iowa, USA)	22	26	*N*-EtFOSAA (3.6 ng/l)	Domestic influent (no known manufacturing or industrial perfluorochemical source)	Boulanger et al., 2005
10 WWTPs (USA)	3–97	1–130	PFBS, PFHxS, 6:2 FtS, PFHxA, PFNA, PFDA, FOSA	Domestic, industrial, and commercial influents	Schultz et al., 2006
6 WWTPs (New York, USA)	58–1050	3–68	PFHxS, PFNA, PFDA, PFUnDA, 8:2 FTCA, 8:2 FTUCA	Domestic, industrial, and commercial influents	Sinclair and Kannan, 2006
Reclaimed wastewater, 4 WWTPs (California, USA)	12–185	20–187	PFHxS, PFDS, PFHxA, PFHpA, PFNA, PFDA, 6:2 FtS, FOSA, *N*-EtFOSAA	Domestic, industrial, and commercial influents	present study, 2007
Surface water					
Tennessee river (Decatur, AL, USA) upstream and downstream of fluorochemical manufacturing facility	Upstream: <25; Downstream: <25–513	Upstream: 17-53; Downstream: 30–140	n.m.	Fluorochemical manufacturing facility	Hansen et al., 2002
Etobicoke Creek (Toronto, Ontario, Canada) upstream and downstream of fluorochemical spill over time	Upstream: n.d.-33; downstream: n.d.-10 600	Upstream: n.d.; downstream: n.d.-995 000	PFHxS	Accidental spill of aqueous film-forming foams (AFFFs)	Moody et al., 2002
Lake Erie and Lake Ontario (USA), urban and remote locations	27–50	21–70	*N*-EtFOSAA (4.2–11 ng/l), FOSA (0.6–1.3 ng/l), PFOSulfinate (n.d.-17 ng/l)	Not stated	Boulanger et al., 2004
River (Iowa City, Iowa, USA)	8.7	23	*N*-EtFOSAA (1.2 ng/l)	Wastewater effluent	Boulanger et al., 2005
"Remote" lakes (Lake Superior, Minnesota, USA; Voyageurs National Park lakes, Canada)	0.1–0.7	n.d.-1.2	PFHxA, PFHpA, PFNA	Atmospheric deposition	Simcik and Dorweiler, 2005
"Urban" waters (3 lakes in Minneapolis and Minnesota River in Minnesota, USA)	0.5–19	2.4–47	PFHxA, PFHpA, PFNA, PFDA	Urban location, runoff, and wastewater discharge	Simcik and Dorweiler, 2005
Lake Michigan (USA)	0.3–3.4	0.9–3.1	PFHpA	Non-atmospheric sources	Simcik and Dorweiler, 2005
Streams, lake in Shihwa and Banweol industrial areas, South Korea	0.9–62	2.2–651	PFBS, PFHxS, FOSA, PFHxA, PFHpA, PFDA	Local industrial sources	Rostkowski et al. (2006)
Surface waters of New York state, USA	<0.5–7.4	<0.8–756	PFHxS	Industrial and municipal wastewater effluent	Sinclair et al., 2006
Rhine river, Moehne river, and their tributaries (Germany)	2–48 (Rhine); 11–33 900 (Moehne)	2–26 (Rhine); 2–5900 (Moehne)	PFBS, PFBA, PFPnA, PFHxA, PFHpA	Superficial run-off from waste materials applied to agricultural areas upstream; wastewater discharge	Skutlarek et al., 2006
Tributaries of the Pearl and Yangtze Rivers (China)	0.85–260	<0.01–99	PFBS, PFHxS, FOSA, PFHxA, PFHpA, PFNA, PFDA, PFUnA	Industrial and municipal wastewater effluent	So et al., 2007
European rivers including Po, Rhine, Danube, Elbe, Oder, Seine, and Loire	200 (Po River) <0.65–23 (other rivers)	n.m.	PFHxA, PFHpA, PFNA	Fluoropolymer manufacturing facilities present in Po watershed; wastewater effluent is a likely source for the other rivers	McLachlan et al., 2007
Constructed wetland receiving reclaimed wastewater (California, USA)	9–14	19–29	PFHxS, PFDS, PFHxA, PFHpA, PFNA, PFDA, FOSA, *N*-EtFOSAA	Wastewater effluent	Present study, 2007
Upper Silver and Coyote Creeks (San Jose, CA, USA)	8–36	5–56	PFHxS, PFDS, PFHxA, PFHpA, PFDA, FOSA, *N*-EtFOSAA	Urban location, runoff, and atmospheric deposition	Present study, 2007
Groundwater					
Wurtsmith air force base (Michigan, USA)	8000–105 000	4000–110 000	PFHxS, PFHxA	Past fire-training exercises using AFFFs	Moody et al., 2003
Wurtsmith (Michigan, USA) and Tyndall (Florida, USA) Air Force Bases	3000–6 570 000	4000–2 300 000	4:2 FtS, 6:2 FtS, 8:2 FtS	Past fire-training exercises using AFFFs	Schultz et al., 2004
Monitoring wells near Upper Silver and Coyote Creeks (San Jose, CA, USA)	n.d.-18	19–87	PFHxS, PFDS, PFHxA, PFHpA, PFDA, FOSA, *N*-EtFOSAA	Infiltration from overlying urban stream, possibly other sources	Present study, 2007
Rainwater					
Winnipeg, Manitoba, Canada	n.d.	0.6	FTCAs, FTUCAs	Degradation from volatile fluorotelomer alcohols and other precursors	Loewen et al., 2005