Fate of Pharmaceuticals, Personal Care Products, and Endocrine-disrupting Chemicals in Water

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Introduction

Pharmaceuticals (both prescription- and non-prescription drugs) and personal care products (combined and termed as PPCPs, hereafter) and endocrine-disrupting chemicals (termed as EDCs, hereafter) have recently been identified as emerging organic contaminants in environmental waters (Xagoraraki and Kuo, 2008; Sanderson et al., 2004; Christensen, 1998; Schulman et al., 2002; Webb et al., 2003; Schwab et al., 2005; Bercu et al., 2008; Snyder, 2008; Cunningham et al., 2009). Personal care products (PCPs) represent a group of chemicals, which can be categorized based on their intended usages: (1) Cosmetics (e.g., triethyl citrate), (2) Antimicrobial activity (e.g., triclosan), (3) Deodorizer (e.g., 1,4-Dichlorobenzene), (4) Fragrance (e.g., 3-Methyl-1*H*-indole (skatol)), and (5) Flavorant (e.g., Camphor) *(*Stackelberg *et al.*, 2004*)*. Endocrine-disrupting chemicals (EDCs) represent groups of chemicals which have been reported to result in increased incidences of breast, prostate, and testicular cancers, reproductive disorders, cognitive impairment, miscarriage, early puberty in girls, delayed puberty in boys, impaired fertility in men, cognitive impairment, behavior abnormalities in children, etc. *(*Birklett, 2003; Liu *et al.*, 2005; Rahman *et al.*, 2009*)*. In general, these organic compounds can be categorized in five categories: (1) Pharmaceuticals, (2) Steroids, (3) Alkylphenols, (4) Flame retardants, and (5) Pesticides *(*Liu *et al.*, 2005; Stackelberg *et al.*, 2007*)*. The presence of these organic compounds in wastewater effluent and source water for drinking water utilities may have implications on human and ecological health.

Water and wastewater treatment processes are capable of transforming PPCPs and EDCs, but each compound responds differently to treatment, making it difficult to predict the fate of these chemicals as a whole. A review of literature suggests that conventional water treatment may effectively remove the majority of tested chemicals. However, certain compounds appear to undergo treatment without transformation, thus requiring further treatment. Drinking water oxidants, such as chlorine, ozone, and advanced ultraviolet (UV) oxidation have been shown to degrade and transform a wide variety of PPCPs and EDCs. Chlorine and ozone are shown to react with these emerging contaminants during water treatment and often results in the formation of by-products that may or may not be harmful to humans and the environment. In most cases, UV irradiation does not degrade emerging contaminants unless an advanced oxidation process (AOP), such as H_2O_2/ozone is applied. Ozone appears to be the most effective at oxidizing different classes of emerging contaminants present in waters. Predictive quantitative-structure-activity-relationship (QSAR) models may be key to determining persistence of these chemicals during drinking water treatment. However, the current state of knowledge does not provide clear answers regarding potential human risks of exposure to emerging contaminants via water consumption and/or recreational activities.

Sources and Occurrences

Contamination of aquatic systems with PPCPs and EDCs has become an emerging important environmental issue for health of human-beings and environment. These organic

compounds are biologically active compound, which may produce adverse effects in humans, animals, and plants. Increasing numbers of studies reveal that these chemicals have been found in natural waters, wastewater effluents, and drinking water supplies. When water undergoes treatment, such as coagulation/flocculation, adsorption, disinfection/oxidation, these chemicals are either removed from water or transformed into compounds that are less or more harmful to humans and the environment than the parent compound (Rahman *et al.*, 2009). Removal of these compounds from water primarily depends on their initial concentrations, characteristics of water matrix, sequence and conditions of different unit-processes at drinking and wastewater treatment plants. In the United States there is more consumption of new pharmaceuticals and high-strength or long-acting formulations than in other countries *(*Danzon and Furukawa, 2008*).* This suggests that more persistent and/or newer man-made compounds may occur in U.S. waters. A recent USGS survey of 139 streams in 30 states, conducted by Kolpin *et al.* (2002), reported detection of 82 of 95 target compounds, including steroids, plasticizers, detergent metabolites, veterinary medicines, and other organic water contaminants.

Sources of PPCPs and EDCs in Environment

There are several proposed pathways responsible for contamination of water with these organic compounds. Pharmaceuticals consumed by humans in daily life are partially metabolized and excreted into wastewater in forms of urine and fecal matter. Depending on removal efficiencies of unit processes at wastewater treatment plant and contaminant's initial concentrations, a portion of these contaminants, either transformed or unchanged, are released in wastewater effluents and discharged in receiving water bodies. These contaminants are found in surface water or groundwater bodies, depending on their persistence in environment. During the use of surface stream as a source of raw water for supplying drinking water after treatment, these contaminants enter into drinking water treatment system and are removed depending on removal effectiveness of different unit processes present in the drinking water treatment system. At drinking water treatment plant, these compounds are either removed or transformed to other compounds (i.e., by-products). Upon distribution of drinking water for human consumption, these compounds and their by-products are present in water, which finally results in exposure of humans to these contaminants through ingestion of drinking water.

In addition to wastewater, animal waste, biosolids, and solid waste are other possible sources of PPCPs and EDCs in environment. Animal production has been reported to contribute significantly in dissemination of pharmaceuticals in water, particularly from industrialized animal agriculture, or from concentrated animal feeding operations (CAFOs). Industrialized animal agriculture is used to provide livestock for human consumption, typically with animals living in dense populations. After a period of storage manure is often land-applied as plant fertilizer, and as consequence the pharmaceuticals are discharged to surface and ground water via surface runoff and percolation. Studies indicate application of swine manure to crops results in temporary increases of antibiotic resistant bacteria *(*Sengelov *et al.*, 2003; Halling-Sorensen *et al.*, 2005*).*

Occurrences

Pharmaceuticals and personal care products (PPCPs) in Water

The presence of pharmaceuticals and personal care products (PPCPs) in raw and treated wastewater has been well documented with concentrations averaging from less than 10 µg/L in finished wastewater to greater than 100 µg/L in raw wastewater *(*Batt *et al.*, 2006; Boyd *et al.*,

2003; Brun *et al.*, 2006; Buser *et al.*, 1999; Buser *et al.*, 1998; Carballa *et al.*, 2004; Castiglioni *et al.*, 2006; Wennmalm and Gunnarsson, 2005; Yang and Carlson, 2004; Zuccato *et al.*, 2006*)*. Examples of pharmaceuticals that have been detected in wastewater are common prescription and veterinary drugs such as beta-blockers (*e.g.*, metoprolol, propranolol), analgesics (*e.g.*, ibuprofen, naproxen), and antibiotics (*e.g.*, erythromycin, trimethoprim, ciprofloxacin, tetracylcline, clindomycin, sulfonamides, tetracycline, fluoroquinolone, macrolides, and trimethoprim). For example, Santos *et al.*, (2007) detected ibuprofen in wastewater influent and effluent at concentrations of 12.1 – 373 µg/L and 0.78 – 48.2 µg/L, respectively. Naproxen was also detected at 1.1 – 27.4 µg/L in wastewater influent and 0.22 – 4.3 µg/L in effluent. Gomez *et al.* (2007) detected acetaminophen, codeine, diclofenac, and ibuprofen in wastewater influent at mean concentrations of 134, 5.2, 1.5, and 84 µg/L, and in wastewater effluent at mean concentrations of 0.22, 3.7, 0.9, and 7.1 µg/L, respectively.

Although most of the published literature focuses on occurrence in sewage effluents, PPCPs have also been detected in raw and treated drinking water, mostly at levels less than 1 µg/L *(*Boyd *et al.*, 2003; Heberer, 2002; Loraine and Pettigrove, 2006; Moll *et al.*, 2001; Perret *et al.*, 2006; Petrovic *et al.*, 2003; Rodriguez-Mozaz *et al.*, 2004; Stackelberg *et al.*, 2004; Stolker *et al.*, 2004; Ternes *et al.*, 2002; Vieno *et al.*, 2005; Zuhlke *et al.*, 2004*)*. For example, Loraine and Pettigrove (2006) detected ibuprofen in finished drinking water at a mean concentration of 0.93 µg/L. In Italy, three sulfonamide antibiotics were detected in store-bought mineral waters at concentrations ranging from 0.009 to 0.080 µg/L *(*Perret *et al.*, 2006*)*. In 2004, the US Geological Survey conducted a study on the fate of 106 contaminants throughout a conventional drinking water treatment plant *(*Stackelberg *et al.*, 2004*)*. Pharmaceuticals present in raw water samples included carbamazepine, trimethoprim, erythromycin-H_2O, acetaminophen, codeine, and sulfamethoxazole. Carbamazepine was detected at a maximum concentration of 0.258 µg/L in finished water samples *(*Stackelberg *et al.*, 2004*)*.

The presence of PPCPs has been confirmed in surface waters (rivers and lakes) as well, with concentrations generally less than 1 µg/L *(*Abuin *et al.*, 2006; Batt *et al.*, 2006; Bound and Voulvoulis, 2006; Yang and Carlson, 2004; Zuccato *et al.*, 2006*)*. For example, Bound and Voulvoulis (2006) reported concentrations of ibuprofen and acetaminophen up to 3 and 0.56 µg/L, respectively. Rabiet *et al.* (2006) detected acetaminophen, carbamazepine, and diclofenac in surface water at concentrations of 0.011 – 0.072, 0.024 – 0.056, and 0.001 – 0.033, respectively. The U.S. Geological Survey conducted the first major study of pharmaceuticals and personal care products in surface waters during 1999 and 2000 *(*Kolpin *et al.*, 2002*)*. The study focused on locations likely to be contaminated by wastewater effluent. Kolpin *et al.* (2002) detected pharmaceuticals, steroids and hormones, veterinary and human antibiotics, and other organic contaminants in 80% of 139 streams sampled. The most frequently detected pharmaceuticals by Kolpin *et al.* in U.S. streams included trimethoprim, acetaminophen, erythromycin, estriol, lincomycin, and sufamethoxazole at detection frequencies of 27.4, 23.8, 21.5, 21.4, 19.2 and 19.0% and at median concentrations of 0.013, 0.11, 0.1, 0.019, 0.06, and 0.07 µg/L, respectively. Other pharmaceuticals that have been found in surface waters are naproxen, clofibric acid, ketoprofen and clarithromycin. Frequencies of occurrences of these chemicals, obtained from Kolpin *et al.* (2002). Among all PCPs, fragrances in surface waters have been analyzed more in detail compared to other PCPs (Lee *et al*., 2003a) and have been found as high as 0.150 ug/L in surface waters and 0.1 ug/L in drinking waters.*(*Daughton and Ternes (2002); Kolpin *et al*. (2002) ; Lee *et al*. (2003a); Stackelberg *et al.*, 2007*)*

Table 1. Personal Care Products in Source and Finished Waters

Chemical	CASRN	Source water (µg/L)	Finished water (µg/L)	Reference
Cosmetics				
Triethyl citrate	77-93-0	0.085	0.013	Stackelberg *et al.* (2007)
Antimicrobial				
Triclosan	3380-34-5	0.05-0.15	ND	Daughton and Ternes (2002); Stackelberg *et al.* (2007)
Deodorizer				
1,4-Dichlorobenzene	106-46-7	0.09	ND	Kolpin *et al*. (2002); Stackelberg *et al.* (2007)
Fragrance				
3-Methyl-1*H*-indole (skatol)	83-34-1	ND	ND	Stackelberg *et al.* (2007)
Acetyl hexamethyl tetrahydro naphthalene (AHTN)	21145-77-7	0.126	0.036	Stackelberg *et al.* (2007)
Musk Ketone	81-14-1	0.001-0.023	ND	Lee *et al*. (2003a)
Flavorant				
Camphor	76-22-2	0.004	0.003	Stackelberg *et al.* (2007)
Insect Repellent				
N,N-diethyltoluamide	134-62-3	0.06-0.082	0.003	Kolpin *et al*. (2002)

CASRN-Chemical Abstracts Services Registry Number, ND-Not detected

Endocrine-disrupting Chemicals in Water

Endocrine-disrupting chemicals (EDCs) have been found in stream water and wastewater effluents, along with other organic compounds. The USGS study of national streams *(*Kolpin *et al.*, 2002*)* found occurrences of EDCs with other organic compounds. Similar observations of co-occurrence of EDCs with other wastewater organic compounds were also noted by Stackelberg *et al.* (2007). This study found presence of different EDCs such as bisphenol A (BPA), 4-Nonylphenol (NP), Diethoxyoctylphenol (OP_2EO), Tris(dichloroisopropyl)phosphate (TDIP), and Tris(2-chloroethyl)phosphate (TCEP) with organic compounds in wastewater. Concentrations of EDCs in source water vary between 0.038 and 0.342 µg/L and vary between 0.004 and 0.092 µg/L in finished water. Also, these compounds have been found in settled sludge and filter-backwash sediments, which are of cause of concern as these sediments are generally digested, dewatered, and finally used as a soil amendment.

154 **Table 2 Endocrine disrupting chemicals in stream water (Kolpin et al., 2002)**

Chemical	CASRN	Use	Frequency of detection (%)
Triclosan	3380-34-5	antimicrobial disinfectant	57.6
4-nonylphenol	251-545-23	nonionic detergent metabolite	50.6
Bisphenol A	80-05-7	Plasticizer	41.2
Diazinon	333-41-5	Insecticide	25.9
Methyl parathion	298-00-0	Disinfectant	24.7
Carbaryl	63-25-2	Insecticide	16.5
Benzo(a)pyrene	50-32-8	PAH	9.4
Lindane	58-89-9	Insecticide	5.9
cis-chlordane	5103-71-9	Insecticide	4.7
Dieldrin	60-57-1	Insecticide	4.7
2,6-di-tert-butylphenol	128-39-2	Antioxidant	3.5
3-tert-butyl-4-hydroxy anisole	25013-16-5	Antioxidant	2.4
Prescription drugs			
Fluoxetine	54910-89-3	Antidepressant	1.2
Steroids and hormones			
Estriol	50-27-1	reproductive hormone	21.4
17a-ethynyl estradiol	57-63-6	ovulation inhibitor	15.7
cis-androsterone	53-41-8	urinary steroid	14.3
19-norethisterone	68-22-4	ovulation inhibitor	12.8
17b-estradiol	50-28-2	reproductive hormone	10
mestranol	72-33-3	ovulation inhibitor	10
Estrone	53-16-7	reproductive hormone	7.1
17a-estradiol	57-91-0	reproductive hormone	5.7
progesterone	57-83-0	reproductive hormone	4.3
equilenin	517-09-9	estrogen replacement	2.8
testosterone	58-22-0	reproductive hormone	2.8
Equilin	474-86-2	estrogen replacement	1.4

155

Table 3. Other chemicals (Non-EDC) in stream water (Kolpin et al., 2002)

Chemical	CASRN	Use	Frequency of detection (%)
Veterinary and human antibiotics			
erythromycin-H2O	114-07-8	erthromycin metabolite	21.5
Lincomycin	154-21-2	Antibiotic	19.2
Tylosin	1401-69-0	Antibiotic	13.5
sulfamethoxazole	723-46-6	Antibiotic	12.5
trimethoprim	738-70-5	Antibiotic	12.5
roxithromycin	80214-83-1	Antibiotic	4.8
sulfamethazine	57-68-1	Antibiotic	4.8
ciprofloxacin	8585721-33-1	Antibiotic	2.6
chlortetracycline	57-62-5	Antibiotic	2.4
sulfamerazine	122-11-2	Antibiotic	1.2
Tetracycline	60-54-8	Antibiotic	1.2
sulfamethizole	144-82-1	Antibiotic	1
Norfloxacin	70458-96-7	Antibiotic	0.9
Steroids and hormones			
coprostanol	360-68-9	fecal steroid	85.7
Cholesterol	57-88-5	plant/animal steroid	84.3
Prescription drugs			
Dehydronifedipine	67035-22-7	Antianginal	14.3
Diltiazem	42399-41-7	antihypertensive	13.1
Codeine	76-57-3	Analgesic	10.6
Cimetidine	51481-61-9	Antacid	9.5
Metformin	657-24-9	Antidiabetic	4.8
Gemfibrozil	25812-30-0	antihyperlipidemic	3.6
Enalaprilat	76420-72-9	eantihypertensive metabolite	1.2
Other organics			
N,N-diethyltoluamide	134-62-3	insect repellant	74.1
tri(2-chloroethyl)phosphate	115-96-6	fire retardant	57.6
ethanol,2-butoxy-phosphate	78-51-3	Plasticizer	45.9
Fluoranthene	206-44-0	PAH	29.4
Pyrene	129-00-0	PAH	28.2
1,4-dichlorobenzene	106-46-7	Deodorizer	25.9
4-methyl phenol	106-44-5	disinfectant	24.7
tetrachlorothylene	127-18-4	solvent,degreaser	23.5
phthalic anhydride	85-44-9	plastic manufacturing	17.6
Non-prescription drugs			
Caffeine	58-08-2	Stimulant	61.9
Cotinine	486-56-6	nicotine metabolite	38.1
1,7-dimethylxanthine	611-59-6	caffeine metabolite	28.6
acetaminophen	103-90-2	Antipyretic	23.8
ibuprofen	15687-27-1	antiflammatory	9.5

A: fod >80%, B: 60<fod<80, C: 40<fod<60, D: 20<fod<40, E:fod<20

Removal of PPCPs and EDCs in Drinking Water Utilities

The fate of pharmaceuticals and personal care products (PPCPs), and endocrine-disrupting chemicals (EDCs) during water treatment depends on the compound's physicochemical properties and the types and sequences of processes used in the treatment plant. Physical processes, such as settling, coagulation/flocculation, and filtration show varying removal efficiencies of pharmaceuticals *(*Gobel *et al.*, 2007; Nakada *et al.*, 2007; Stackelberg *et al.*, 2007; Peng *et al.*, 2006; Clara *et al.*, 2005; Ternes *et al.*, 2002*)*. Disinfection processes, such as chlorine oxidation and ozonation are expected to degrade these organic compounds or transform them into byproducts, which may or may not be toxic to humans and environment. PPCPs and EDCs are organic substances which are expected to be highly susceptible to oxidation, depending on their physicochemical properties, such as octanol-water partition coefficient, presence of aromatic rings and functional groups. Full-scale treatment studies indicate that an appropriate combination of processes may effectively reduce their concentrations in water leaving a drinking water treatment plant *(*Nakada *et al.*, 2007; Stackelberg *et al.*, 2007; Boyd *et al.*, 2003; Ternes *et al.*, 2002*)*.

PPCPs and EDCs in Full-scale Drinking Water Treatment Plants

PPCPs. Few studies have looked at removal of pharmaceuticals during full-scale drinking water treatment. Full-scale treatment studies are valuable because they provide information regarding the effectiveness of individual processes on pharmaceutical removal, as well as concentrations of pharmaceuticals in source and finished waters.

Stackelberg *et al.* (2007) sampled water from a drinking water treatment plant (DWTP) in the United States that utilized screening, clarification, primary chlorine disinfection, sand/granular activated carbon (GAC) filtration, and secondary chlorine disinfection. The DWTP treated 235 million liters per day. The degree of removal by each process varied for each organic compound investigated. Forty-five organic compounds were detected in the source water, including pharmaceuticals, flame retardants, plasticizers, pesticides, and others. Overall, GAC filtration resulted in an average percent removal of 53% for all compounds, disinfection resulted in 32% removal, and clarification resulted in 15% removal. Only some of the pharmaceuticals, such as acetaminophen, carbamazepine, erythromycin, and sulfamethoxazole were detected in at least 25% of source water samples. After primary disinfection, sulfamethoxazole and acetaminophen were not detected, while carbamazepine and erythromycin were removed by 20% and 92%, respectively. The initial concentrations of acetaminophen, carbamazepine, erythromycin, and sulfamethoxazole compounds before primary disinfection were 30, 15, 191, and 10 ng/L, respectively. The combination of clarification, chlorine disinfection, and sand/GAC filtration was effective at reducing the studied pharmaceuticals. These results were similar to a previous study, which Stackelberg *et al.* (2004) conducted at the same DWTP. The utility was located in a very urbanized area, with at least 50 wastewater treatment plants discharging into streams or tributaries supplying source water to the DWTP. In the original study, the treatment process train followed screening, the addition of powdered activated carbon (PAC), coagulation, primary disinfection, flocculation, sedimentation, sand/GAC filtration, and secondary disinfection. Several changes were made to the treatment process before the second study *(*i.e., Stackelberg *et al.*, 2007*)*, including discontinuing the addition of PAC, adding microsand to the clarification process, and reversing the order of clarification and primary disinfection. Similar to the second study *(*i.e., Stackelberg *et al.*, 2007*)*, carbamazepine was the only investigated pharmaceutical that was not entirely removed by

conventional drinking water treatment (i.e., Stackelberg *et al.*, 2004). Observed removal of organic compounds during drinking water treatment was attributed to hydrophilicity and reactivity of organic compounds and conditions at unit processes, such as oxidant dose, contact time, and presence of co-ions and co-organic compounds, etc.(Stakelberg *et al.*, 2007). GAC removed both hydrophilic and hydrophobic pharmaceuticals, such as carbamazepine (Octanol-water partition coefficient: log K_{OW} = 2.45) compared to chlorination, which only oxidized hydrophilic compounds.

A treatment train consists of clarification, disinfection, and filtration steps was observed to be effective in removing only one personal care product (PCP) out of 4 PCPs studied during a monitoring study which Stackelberg *et al.* (2007) conducted at a DWTP . Only triethyl citrate was observed to removed ~90% from water compared to other PCPs, such as acetyl hexamethyl tetrahydro naphthalene (AHTN) and hexahydrohexamethyl cyclopentabenzopyran (HHCB), which were observed to removed <20%. Further, they also observed that the same treatment train was able to remove >50% EDCs from water. Summary of performance effectiveness of overall treatment train of the DWTP in removing EDCs, such as bisphenol A (BPA), tris(2-chloroethyl)phosphate (TCEP), 4-nonylphenol (NP), diethoxyoctylphenol (OP_2EO), and tris(dichloroisopropyl)phosphate (TDIP) from water. EDCs such as TCEP, OP_2EO, and TDIP were observed to be completely removed from water in the DWTP (i.e., 100% removal), whereas BPA and NP were observed to be removed only by 87% and 68%, respectively.

Boyd *et al.* (2003) took samples at various stages of treatment from two different drinking water treatment plants. The first plant situated in Louisiana, USA, used PAC addition, coagulation, flocculation, sedimentation, chlorination, filtration, and chloramination steps for drinking water treatment. Only naproxen was detected at 68 ng/L, but it was completely removed after going through a combination of unit processes, consists of chlorination, filtration, and chloramination steps. The second plant, located in Windsor, Ontario, used ozonation, coagulation, flocculation, sedimentation, filtration, and chlorination steps for drinking water treatment. In this plant, clofibric acid and naproxen were detected in the influent raw water at 103 ng/L and 63 ng/L, respectively. Neither of the compounds was detected in the final effluent.

Ternes *et al.* (2002) also monitored selected pharmaceuticals from two different drinking water treatment plants. The first DWTP used pre-ozonation, flocculation, main ozonation, multiple-layer filtration, and GAC filtration steps for the treatment train, while the other plant used sedimentation, flocculation, GAC filtration, underground passage, bank filtration, and slow sand filtration steps. During the study, Ternes *et al.* (2002) observed the combination of ozonation and GAC filtration steps effective at reducing carbamazepine, diclofenac, and clofibric acid compounds, with all three compounds removed by greater than 90% in the first treatment plant (initial concentrations of these compounds ranged from 10 to 180 ng/L).

Bundy *et al.* (2007) studied effects of drinking water treatment processes, such as flocculation, sedimentation, dual-media filtration (anthracite and sand), GAC, and chlorine disinfection removal of pharmaceuticals and pharmaceuticals-like compounds, such as caffeine (1μg/L), trovafloxacin (38 μg/L), 17β-Estradiol (1μg/L), and salicyclic acid (3 μg/L) from water. During this study, the filtration step was observed to partially some of the compounds studied. It was observed to provide 0.62 to 7.7% removal of caffeine and estradiol and 3.3 to 27.1% removal for trovafloxacin compounds. For these chemicals, the disinfection was not observed to be effective. Addition of a GAC adsorber to unit processes resulted in increase in overall removal of PPCPs and EDCs to more than 90% for all chemicals tested.

250 **Table 4. Overall Removal of Pharmaceuticals during Full-Scale Drinking Water Treatment**

Pharmaceutical	Frequency of detection in stream water (>10%)	Influent Concentration (ng/L)	Effluent Concentration (ng/L)	Overall Removal (%)	Treatment Process Train	Reference
Carbamazepine		191[a] 200[a,b] 80 80 - 180[b]	29[a] 126.5[a,b] BDL BDL – 30[b]	85 36.7[a] >99 83 – 100[c]	Screening, clarification, chlorination, sand/GAC filtration, secondary chlorination Screening, PAC and sulfuric acid addition, coagulation, chlorination, flocculation, sedimentation, GAC filtration, secondary chlorination DWTP1: Pre-ozonation, flocculation, main ozonation, layer and GAC filtration DWTP2: Sedimentation, flocculation, GAC, underground passage, bank and sand filtration	Stackelberg *et al.*, 2007[c] Stackelberg *et al.*, 2004 Ternes *et al.*, 2002
Bezafibrate		80[b] ND	BDL	100[c]	DWTP1: Pre-ozonation, flocculation, main ozonation, layer and GAC filtration DWTP2: Sedimentation, flocculation, GAC, underground passage, bank and sand filtration	Ternes *et al.*, 2002
Clofibric Acid		~10[b] ~10-15[b]	BDL BDL	100[c] 100[c]	DWTP1: Pre-ozonation, flocculation, main ozonation, layer and GAC filtration DWTP2: Sedimentation, flocculation, GAC, underground passage, bank and sand filtration	Ternes *et al.*, 2002
Diclofenac		~35[b] ~65[b]	BDL BDL	100[c] 100[c]	DWTP1: Pre-ozonation, flocculation, main ozonation, layer and GAC filtration DWTP2: Sedimentation, flocculation, GAC, underground passage, bank and sand filtration	Ternes *et al.*, 2002
Naproxen		63-65 64	ND ND	100 100	DWTP1: PAC addition, coagulation/flocculation/sedimentation, chlorination, filtration, chloramination DWTP2: Ozonation, coagulation/flocculation/sedimentation, filtration, chlorination	Boyd *et al.*, 2003
Veterinary and						

human antibiotics						
Erythromycin	21.5 (Kolpin et al., 2002)	10[a]	ND	100	Screening, clarification, chlorination, sand/GAC filtration, secondary chlorination	Stackelberg *et al.*, 2007[c]
Sulfamethoxazole	19% (Kolpin et al., 2002)	30[a]	ND	100	Screening, clarification, chlorination, sand/GAC filtration, secondary chlorination	Stackelberg *et al.*, 2007[c]
Prescription drugs						
Codeine	10.6% (Kolpin et al,, 2002)					
Dehydronifedipine	14.3% (Kolpin et al,, 2002)					
Dilitiazem	13.1% (Kolpin et al., 2002)					
Non-prescription drugs						
Acetaminophen	23.8 (Kolpin et al., 2002)	15[a]	0.3[a]	98	Screening, clarification, chlorination, sand/GAC filtration, secondary chlorination	Stackelberg *et al.*, 2007[c]
Cotinine	38.1 (Kolpin et al., 2002)					

Note: BDL: below detection limits; NA: not available; ND: pharmaceutical not detected in sample; NM: not measured

[a] Value represents average.

[b] Approximated from figure.

[c] Removal calculated by authors.

257 **Table 5. Overall Removal of Endocrine-disrupting chemicals during Full-Scale Drinking Water Treatment**

Pharmaceutical	Frequency (%) (Kolpin et al., 2002)	Influent Concentration (ng/L)	Effluent Concentration (ng/L)	Overall Removal (%)	Treatment Process Train	Reference
Other organics						
Triclosan	57.6	ND	ND	-	Screening, clarification, chlorination, sand/GAC filtration, secondary chlorination	Stackelberg et al., 2007
4-nonylphenol	50.6	342	92	73	Screening, clarification, chlorination, sand/GAC filtration, secondary chlorination	Stackelberg et al., 2007
Bisphenol A	41.2	107	26	76	Screening, clarification, chlorination, sand/GAC filtration, secondary chlorination	Stackelberg et al., 2007
Diazinon	25.9	47	ND	100	Screening, clarification, chlorination, sand/GAC filtration, secondary chlorination	Stackelberg et al., 2007
Methyl parathion	24.7					
Carbaryl	16.5	55	ND	100	Screening, clarification, chlorination, sand/GAC filtration, secondary chlorination	Stackelberg et al., 2007
Chlorpyrifos	15.3					
Diethylphthalate	11.1					
bis(2-ethylhexyl)phthalate	10.6					
2,6-di-tert-butyl-1,4-benzoquinone	9.4					
Benzo(a)pyrene	9.4	ND	ND	-	Screening, clarification, chlorination, sand/GAC filtration, secondary chlorination	Stackelberg et al., 2007

258 Note: BDL: below detection limits; NA: not available; ND: pharmaceutical not detected in sample; NM: not measured
259 [a] Value represents average.
260 [b] Approximated from figure.
261 [c] Removal calculated by authors.

262

Table 6. Removal of Pharmaceuticals during Individual Processes in Full-Scale Drinking Water Utilities

Chemical	Influent Conc. (ng/L)	Primary Treatment (Coagulation, flocculation, settling)		Filtration			Disinfection			Reference
		ng/L	% Removal	Ng/L	% Removal	Type	ng/L	% Removal	Oxidant	
Carbamazepine	191[a] 200[a,d] 80-180[d]	186[a] 82.3 [a,d] 100 – 180[d]	3[b] 59.9 [a, b] 0 to 14[b]	4[a] 106 [a,d] 0 - 10[d]	97 [b] 0 [a, b] >90[b]	Sand/GAC GAC GAC	149[a] 126.5 [a,d] NA	20 [b] 0[a,b] >99[e]	NaOCl NaOCl Ozone	Stackelberg *et al.*, 2007[c] Stackelberg *et al.*, 2004 Ternes *et al.*, 2002
Bezafibrate	80[d]	73[d]	8.8[b]	BDL	>95[b]	GAC	NM	NM	Ozone	Ternes *et al.*, 2002
Clofibric Acid	9 - 10[d]	10[d]	0[b]	5[d]	50[b]	GAC	NA	77[e]	Ozone	Ternes *et al.*, 2002
Diclofenac	35 – 65[d]	60[d]	7.7[b]	BDL	>95[b]	GAC	NA	>99[e]	Ozone	Ternes *et al.*, 2002
Naproxen	63-65	63-68	0[b]	NA	NA	NA	ND[e]	100[b]	NaOCl	Boyd *et al.*, 2003
Veterinary and human antibiotics										
Erythromycin	10[a]	5.3[a]	47[b]	ND[a]	100[b]	Sand/GAC	0.4[a]	92[b]	NaOCl	Stackelberg *et al.*, 2007[c]
Sulfamethoxazole	30[a]	20[a]	33[b]	ND[a]	NA	Sand/GAC	ND[a]	100[b]	NaOCl	Stackelberg *et al.*, 2007[c]

Note: Percent removals were calculated based on pharmaceutical concentration before and after each treatment process (eg. primary treatment, filtration, disinfection).
BDL: below detection limit; NA: not available; ND: pharmaceutical not detected in sample; NM: not measured
[a] Value represents average.
[b] Authors calculated removals from given concentrations.
[c] Filtration followed primary disinfection.
[d] Approximated from figure.
[e] Removal after main ozonation

Table 7. Removal of EDCs during Individual Processes in Full-Scale Drinking Water Utilities

Chemical	Influent Conc. (ng/L)	Clarification		Disinfection			Filtration			Reference
		ng/L	% Removal	ng/L	% Removal	Oxidant	ng/L	% Removal	Type	
Other organics										
Tris(2-chloroethyl)phosphate (TCEP)	95	94	-0	92	2.1	Chlorine	ND	100	Sand/ GAC	Stackelberg *et al.* (2007)
Diethoxyoctylphenol (OP_2EO)	38	17	55.3	15	11.7	Chlorine	ND	100	Sand/ GAC	Stackelberg *et al.* (2007)
Tris(dichloroisopropyl) phosphate (TDIP)	102	102	0	101	0	Chlorine	ND	100	Sand/ GAC	Stackelberg *et al.* (2007)
Triclosan										
4-nonylphenol	342	342	-0	100	70.8	Chlorine	108	0	Sand/ GAC	Stackelberg *et al.* (2007)
Bisphenol A	107	108	0	45	58.3		14	68.9	Sand/ GAC	Stackelberg *et al.* (2007)

Note: Percent removals were calculated based on pharmaceutical concentration before and after each treatment process.
ND: pharmaceutical not detected in sample

Removal Effectiveness of Unit Processes in Removing PPCPs and EDCs from Water

This section presents descriptions of removal effectiveness of different unit processes at DWTP, such as (a) lime softening, coagulation/flocculation, sedimentation, (b) filtration (adsorptive, sand, and membrane filtration), and (c) oxidation (chlorination, ozonation, H_2O_2/ozonation, and ultraviolet Irradiation) in reducing concentrations of PPCPs and EDCs in drinking water. Also, a discussion about possible water quality indicators, to be used in ascertaining removal effectiveness of different treatment trains employed at different DWTPs, is presented at the end of this chapter.

a. Lime Softening, Coagulation, Sedimentation

Several studies have investigated the effects of coagulation/flocculation, lime softening, and sedimentation on removal of PPCPs and EDCs from water. Sedimentation by coagulation/flocculation and lime softening are not expected to remove these organic compounds due to their hydrophilic nature (Ternes *et al*., 2002; Westerhoff *et al*., 2005; Kimura *et al*., 2005; Vieno *et al.,* 2007; Stackelberg *et al*., 2007; Choi *et al.*, 2008). Ternes *et al.* (2002) observed little or no removal of carbamazepine, diclofenac, and clofibric acid after coagulation with iron chloride during full-scale drinking water treatment. Similarly, Stackelberg *et al.* (2007) observed incomplete removal of acetaminophen, carbamazepine, erythromycin, and sulfamethoxazole during coagulation with iron chloride at a DWTP. Clarification resulted in percent removals of 3%, 33%, 47%, and 60% for carbamazepine, sulfamethoxazole, erythromycin, and acetaminophen, respectively (Stackelberg *et al.*, 2007). During a bench-scale study, Adams *et al.* (2002) did not observe any removal of antibiotics during coagulation and lime softening processes (experimental conditions: aluminum sulfate concentration: 20-107 mg/L; ferric sulfate concentration: 35-169 mg/L; antibiotics types: carbadox, sulfachlorpyridazine, sulfadimethoxine, sulfamerazine, sulfamethazine, sulfathiazole, and trimethoprim; antibiotic concentration: 50 µg/L; lime dosage: 232 mg/L; soda ash dosage: 191 mg/L; pH 11.3). Westerhoff *et al.* (2005) also observed similar results during coagulation and lime softening experiments involving 22 different pharmaceuticals. In a pilot-scale study, the average removal of 13 different pharmaceuticals was 3% during coagulation with ferric sulfate (Vieno *et al.,* 2007). Choi *et al.* (2008) conducted coagulation experiments on tetracycline antibiotics using poly-aluminum chloride (dosage: 5 - 60 mg/L, mixing time: 5 min) and observed that removal of antibiotics increased with increasing coagulant dose. However, removal was observed to decrease at very high dosage, i.e., 40 mg/L, which was attributed to the possibility of charge neutralization of antibiotics at high coagulant dosage, resulting in re-stabilization of antibiotics in water. Analysis of these studies indicates that lime softening and coagulation processes are not effective in completely reducing concentrations of PPCPs in water.

b. Filtration

Three different types of filtrations are considered in this work: (1) Adsorptive filtration, (2) Sand filtration, and (3) Membrane filtration. Following sections present descriptions of performance effectiveness of these filtration types in removing PPCPs and EDCs from drinking water.

Adsorptive Filtration. Adsorption by activated carbon is commonly used in drinking water treatment for removal of organic chemicals, associated with taste and odor and natural organic matter (NOM), either in powdered activated carbon (PAC) or granular activated carbon

(GAC) forms. The adsorption of organic compounds to activated carbon depends on its chemical structure, polarity, and hydrophobicity (expressed in terms of octanol-water partition coefficient, K_{ow}); porosity of activated carbon (i.e., media), activated carbon dosage, and presence of NOM in solution during adsorptive filtration *(*Choi *et al.*, 2008; Mestre *et al.*, 2007; Vieno *et al.*, 2007; Westerhoff *et al.*, 2005; Yoon *et al.*, 2003; Yu *et al.*, 2003; Bundy *et al*., 2007*)*.

Adsorption by GAC may be effective for removing pharmaceuticals with high octanol-water partitioning coefficients (K_{ow}), such as estradiol, ethinylestradiol, fluoxetine, bezafibrate, carbamazepine, and diclofenac compounds *(*Ternes *et al*., 2002; Vieno *et al*., 2007*)*. During a pilot study, Vieno *et al.* (2007) observed that most of the pharmaceuticals studied were removed after a two-step GAC filtration process except those pharmaceuticals having high hydrophillicity (or K_{ow}), such as atenolol, sotalol, and ciprofloxacin. Choi *et al.* (2008) found the use of a coal-based GAC column more effective than coagulation in removing tetracycline (> 68% removal was observed using GAC) and reported that coal-based carbon exhibits slightly better removal than coconut-based carbon for removing pharmaceuticals from water. During a batch adsorption study of removal of bezafibrate, carbamazepine, diclofenac, and clofibric acid compounds from water using a coal-based GAC (chemical concentration range: 0.1-100 μg/L; sorbent concentration: <0.2 g/L; equilibrium time: 24 h), Ternes *et al*. (2002) also observed similar removals and suggested the possibility of application of a coal-based GAC adsorber in drinking water treatment plants.

Addition of powdered activated carbon (PAC) adsorber to drinking water treatment train may also be effective, but is often only used seasonally to control taste and odor causing organic compounds and NOM. PAC adsorber appears to be effective in removing antibiotics from surface water. Adams *et al.* (2002) observed more than 90% removal of antibiotics, such as carbadox, sulfachlorpyridazine, sulfadimethoxine, sulfamerazine, sulfamethazine, sulfathiazole, trimethoprim (antibiotic concentration: 50μg/L; PAC concentration: 50mg/L) from both pure water and surface water (alkalinity: 7 mg/L as $CaCO_3$; total hardness: 268 mg/L as $CaCO_3$; pH 7.7). Westerhoff *et al.* (2005) also found that increasing PAC dosage resulted in greater removal of pharmaceuticals and EDCs, such as bisphenol A (BPA), 17β-estradiol (E2) and 17α-ethynylestradiol (EE2) from water, with a dosage of 20 mg/L PAC removing more than 80% of organic compounds studied. They observed trends of compounds with protonated bases having greater removal than other compounds, particularly compounds with deprotonated functional groups having low K_{ow} values. Yoon *et al.* (2003) investigated the adsorption of EDCs, such as E2 and EE2 onto six different PAC brands, tested at 5 and 15 mg/L dosages and a 4 hour contact time (hormone concentration: 100 nM). For the model water, more than 99% of the hormones were observed to be removed by all brands except for one, which had the lowest point of zero charge (pH_{ZPC}) value. Removals of hormones were observed to lower in raw drinking water because of the presence of NOM, which might have influenced adsorption of hormones on PAC. Snyder *et al.* (2006) studied removal of spiked pharmaceutical compounds from natural waters in bench- and pilot- scale experiments and observed that majority of compounds tested were removed by more than 90% with a PAC dose of 35 mg/L and 5 hour contact time.

The adsorption of organic compounds on activated carbon depends on its chemical structure, polarity, and hydrophobic nature; activated carbon type and dosage, solution pH and presence of co-solutes, such as natural organic matter (NOM) during adsorption *(*Stackelberg *et al*., 2004; Mestre *et al.*, 2007; Suntisukaseam *et al.* 2007*)*. Solution pH is one of the most important parameters, which influence adsorption of organic compounds and thus removal from water. Depending on solution pH, surface characteristics (i.e., pH_{ZPC}) and the extent of

protonation/deprotonation of organic compounds vary. Mestre *et al.* (2007) studied the effect of pH on adsorption of ibuprofen on activated carbon prepared from cork powder, and observed a decrease in removal of ibuprofen with an increase in solution pH, suggesting the role of electrostatic bonding between ibuprofen compound and activated carbon. As ibuprofen has a pK_a value of 4.91, electrostatic repulsion is expected to occur between ibuprofen anion and activated carbon surface at solution pH > 5, resulting in reduction of adsorption of ibuprofen compounds on activated carbon surface. The second most important factor influencing the extent of adsorption is the surface characteristics of media (i.e., activated carbon in this case). To study the effect of surface characteristics of activated carbon on adsorption of acetaminophen and nalidixic acid (a quinolone antibiotic with a carboxylic functional group), Suntisukaseam *et al.*, (2007) used neutral polymeric resin as a polar adsorbent and powdered activated carbon as a nonpolar adsorbent and observed higher adsorption on activated carbon (adsorption isotherm: Freundlich type) compared to polymeric resins (adsorption isotherm: Langmuir type). Also, due to higher water solubility and polarity, acetaminophen was observed to be adsorbed more on both media compared to nalidixic acid. Another important factor influence adsorption of target compounds on GAC is present of co-solutes, specifically NOM, which have been reported to decrease extent of adsorption of organic compounds on GAC. Ternes *et al*. (2002) observed competitive effects of NOM on adsorption of pharmaceuticals on GAC and adsorption of clofibric acid on GAC was observed to be lower in the natural groundwater (dissolved organic carbon: 2.0 mg/L) compared to that in the deionized water. Stackelberg *et al*. (2004) also observed similar effects of NOM in decreasing extent of adsorption of pharmaceuticals, such as carbamazepeine and other organic wastewater-related contaminants (OWCs), on GAC adsorber.

Previous studies have used different types of activated carbons, prepared from different raw materials, such as bituminous carbon, coconut shell, and waste cork powder *(*Yu *et al.*, 2003; Mestre *et al.*, 2007*)* for studying removal of PPCPs and EDCs from water. Yu *et al.* (2003) compared adsorption of naproxen and carbamazepine on activated carbon, prepared from bituminous carbon and coconut shell, using an adsorption isotherm (i.e., Freundlich isotherm) and observed higher adsorption of carbamazepine on carbon than naproxen. Adsorption capacities of these compounds were observed to differ depending on carbon type. Naproxen showed greater adsorption affinity for bituminous carbon than coconut shell, while carbamazepine did not display a significant difference, which was attributed to ionic forms of compounds studied (at experimental conditions studied, naproxen is present in anionic form, whereas carbamazepine is present in a neutral form). Mestre *et al.* (2007) prepared activated carbon using cork powder and studied removal of ibuprofen from water. They observed higher adsorption of ibuprofen on activated carbon prepared using chemical activation method compared to that prepared using physical activation method, and attributed to the effect of porous nature of chemically-activated activated carbon on adsorption.

Sand Filtration. Removal of organic compounds by sand filtration depends on its hydrophilic or hydrophobic characteristics (or octanol-water partition coefficient). For example, Nakada *et al.* (2007) observed lower removal (<50%) for hydrophilic compounds, such as carbamazepine, sulfapyridine, sulfamethoxazole, and estriol after sand filtration compared to hydrophobic compounds, such as ibuprofen, which were removed more than 80% in some cases. During monitoring of a DWTP, Stackelberg *et al.* (2007) observed complete removal of erythromycin, and carbamazepine (~97% removal) during sand/GAC filtration, employed between primary and secondary chlorine disinfection. Ternes *et al.* (2002) also observed similar observations of removal of pharmaceuticals from drinking water in a full-scale DWTP and

reported more than 95% removal of diclofenac and bezafibrate, 75% removal of carbamazepine, and 20% removal of clofibric acid compounds. Not all compounds have been observed to be removed completely by filtration. During the study of removal of pharmaceuticals and pharmaceuticals-like compounds, such as caffeine (1μg/L), trovafloxacin (38 μg/L), 17β-estradiol (1μg/L), and salicyclic acid (3 μg/L) from water, Bundy *et al*. (2007) observed dual-step filtration (consists of anthracite and sand) to provide 0.62 to 7.7% removal of caffeine and estradiol compounds and 3.3 to 27.1% removal of trovafloxacin compounds from water. The filtration step was observed to be more effective than other treatment steps in partially removing some of the compounds studied from water. It appears that sand filtration has a capability of removing these compounds from water, which depends on surface chemical characteristics of organic compounds in water, solution pH, and types and concentrations of co-solutes, however, the treated water requires further treatment to remove low concentrations of different organic compounds in the treated water.

Membrane Filtration. Removal of organic compounds by membrane filtration, similar to sand filtration, also depends on its hydrophilic or hydrophobic nature (or octanol-water partition coefficient), surface characteristics (i.e., pH_{ZPC}), and particle size, and surface characteristics of membrane filters *(*Yoon *et al.*, 2006; Snyder *et al.,* 2006; Verliefde *et al.*, 2007*)*. Depending on filtration type, such as nanofiltration (NF) or ultrafiltration (UF), removal effectiveness of a membrane filtration step for treating water varies *(*Yoon *et al.,* 2006*)*. Yoon *et al.,* (2006) observed that NF membranes retained pharmaceuticals based on its hydrophobic nature and particle size, whereas UF membranes retained pharmaceuticals mainly based on their hydrophobic nature alone. During a study of removal of 20 pharmaceuticals from surface water by a bench-scale nanofiltration (NF) membrane (1500 L/h feed flow, 10% recovery) and by a NF membrane with subsequent GAC column (80% recovery), Verliefde *et al.* (2007) observed rejection values (i.e., removal from water) to be lower for positively charged pharmaceuticals compared to negatively charged pharmaceuticals, for which higher rejection values were observed. Neutral compounds exhibited intermediate removal, likely due to negatively charged membrane surface, or hydrophobic nature of neutral compounds *(*Verliefde *et al.*, 2007*)*. Addition of a GAC adsorber after nanofiltration step was observed to improve overall removal of these compounds from drinking water.

Performance effectiveness of membrane filtration also depends on extent of fouling on membrane filters (or pressure drop across the membrane). Snyder *et al.* (2006) observed very less rejection of pharmaceuticals from feed water by a partially fouled UF membrane. Compounds that were well-removed included steroid hormones, such as estradiol, estrone, ethinylestradiol, and progesterone. During a pilot-study of removal of pharmaceuticals using a reverse osmosis (RO) system, Snyder *et al.* (2006) found that all pharmaceuticals, spiked into feed water, were well-rejected by both virgin and fouled membranes. Similarly, Adams *et al.* (2002) also observed more than 90% rejection rate for antibiotics using a cellulose acetate-based membrane and suggested this to be a viable unit processes for removal of PPCPs from water. However, retentate water, consists of high concentrations of organic compounds, require further treatment prior to being discharged in environment.

c. Disinfection

Disinfection processes, generally used for reducing microbial concentrations in drinking water, have also been reported to degrade organic compounds, including some of the PPCPs and EDCs. Chlorination and ozonation have been extensively used in improving drinking water

quality microbiologically. Different oxidants react differently with organic compounds, such as NOM, and PPCPs and EDCs and reduce their concentrations or transform them into other byproducts *(*Adams *et al*., 2002; Ternes *et al*., 2002; Westerhoff *et al*., 2005; Kumar *et al*., 2006; Saroj *et al*., 2005a & 2005b*)*. The extent and rate of reaction of PPCPs and EDCs primarily depends on solution characteristics (pH, co-solutes), chemical's characteristics (aromatic content, octanol-water partition coefficient), and oxidant type, dosage, and contact time *(*Adams *et al*., 2002; Ternes *et al*., 2002; Westerhoff *et al*., 2005*)*. For example, Westerhoff *et al*. (2005) observed different extent and rate of reactions of chlorine with PPCPs and EDCs. They observed that some compounds, such as acetaminophen, diclofenac, estradiol, estriol, estrone, ethynlestradiol, naproxen, oxybenzone, sulfamethoxazole, and triclosan were highly reactive with chlorine and removed in higher concentrations, whereas, some other compounds, such as DEET, meprobamate, TCEP, BHC, fluorine or heptachlor epoxide were observed to be partly removed. Some functional groups, such as phenol, urea, amino, primary or secondary amine groups were observed to be more reactive with chlorine compared to chlorine-substituted molecules or compounds with conjugated carbon bonds. Similar observations of dependence of extent and rates of reactions of ozone with PPCPs and EDCs were also observed *(*Adams *et al*., 2002; Ternes *et al*., 2002; Westerhoff *et al*., 2005*)*. Ozonation was observed to be more effective in reacting with organic compounds with phenolic groups or aromatic moieties, but less effectives for compounds with ketone, carboxyl functional groups with nonaromatic rings or conjugated bonds *(*Adams *et al*., 2002; Westerhoff *et al*., 2005*)*.

In addition to chlorination and ozonation processes, water utilities have started using other disinfection processes, such as advanced oxidation process (i.e., H_2O_2/ozonation), ultraviolet irradiation, photodegradation, and electrochemical treatment, etc. depending on their performance effectiveness and drinking water quality requirements *(*Westerhoff *et al*., 2005; Korshin *et al*., 2006*)*.

CONCLUSIONS

The presence of PPCPs and EDCs in wastewater, drinking water and surface water is well documented. Primary sources of these organic compounds in surface water are likely from human usage and land application of animal manure. Upon partial removal of these organic compounds in drinking water treatment plant, humans are exposed to low concentrations of these compounds via ingestion of drinking water. Drinking water treatment consists of a train of physicochemical processes, which may or may not remove or transform PPCPs and EDCs into less reactive and toxic compounds. Certain combinations of processes are more effective than others, and bench-scale studies indicate that many factors influence the degree at which these organic compounds are transformed.

Analysis of performance effectiveness of different unit processes in drinking water treatment plant for PPCPs and EDCs indicate that lime softening, coagulation, and sedimentation processes are not effective at removing PPCPs and EDCs. Adsorptive, sand, and membrane filtration processes are effective at removing some of the PPCPs and EDCs compounds, but depends on compound's chemical structure and properties, and filtration media and conditions. Addition of disinfection process, especially chlorination and ozonation processes are very much effective in decreasing remaining concentrations of PPCPs and EDCs from water after coagulation/flocculation and filtration steps at drinking water treatment plant.

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