12. If you are not an advanced Access® user, please note that other tables, queries, forms, and modules are present in the database, but you should not view them. They are used to calculate removal averages. Using the steps above, you can view all data presented and generated in the *CECs Removals Database*.

13. If you are an advanced Access® user, please note that you can view the tables, queries, forms, and modules in the database by clicking the “Open Database View” button on the top, right corner of the Quick Search.

Examples

The following codes are used for the treatment technologies in the *CECs Removals Database*:

Treatment Technology	Subcategories/Variations	Treatment Code
Aerobic granulation	none	AG
Activated sludge	high rate, step feed, oxidation ditch, bardenpho system, conventional, pure oxygen, extended aeration (includes a secondary clarifier for recycle of activated sludge)	ASL
Activated sludge + nutrient removal	activated sludge + nutrient removal (nitrification, denitrification, biological phosphorus removal, etc.)	ASN
Biological activated carbon	none	BAC
Phosphorus removal (biological)	biological	BP
Chlorine disinfection	chlorination, dechlorination, chloramination	CL
Phosphorus removal (chemical)	chemical	CP
Coagulation or softening	addition of chemicals to enhance precipitation of unwanted compounds	CS
Denitrification	separate stage/sludge denitrification	DEN
Electrodialysis	desalination	ED
Electrolysis	none	EL
Fixed film biological treatment	fixed bed reactor, rotating biological contactor, trickling filter	FF
Granular activated carbon	none	GAC
Hydrogen peroxide	usually coupled with UV disinfection or ozonation	H2O2
Ion exchange	magnetic ion exchange resin (MIEX)	ION
Lagoon	none	LAG
Membrane bio reactor	none	MBR
Microfiltration	pore diameter range is 0.09 to 10 micrometers	McF
Media filters	granular media filters, deep bed filters, cloth disc filters; pore diameter range is 10 to 100 micrometers	MF
Nanofiltration	pore diameter range is <0.001 to 0.01 micrometers	NF
Nitrification	separate stage/sludge nitrification	NT
Ozonation + hydrogen peroxide	advanced oxidation process with ozonation and H2O2 coupled	OZ/H2O2
Ozonation + ultraviolet disinfection	advanced oxidation process with ozonation and UV light	OZ/UV
Ozonation	none	OZN
Powdered activated carbon	none	PAC
Reed bed	constructed wetlands	RB
Reverse osmosis	pore diameter range is 0.0001 to 0.005 micrometers	RO
Soil-aquifer treatment	groundwater recharge, natural treatment	SAT
Septic systems	septic tank	SEP
Settling tank	clarification, settling, sedimentation	ST
Ultrafiltration	pore diameter range is 0.004 to 0.1 micrometers	UF
Ultraviolet + hydrogen peroxide	advanced oxidation process with UV light and H2O2 coupled	UV/H2O2
Ultraviolet disinfection	none	UVD

EXAMPLES USING THE TREATMENT SYSTEM OPTION

- Using the treatment system option, the database will calculate removal averages using all treatment systems that include the selected treatment technology(ies).

- When you select a treatment technology, the database will identify all systems that include that treatment technology, regardless of what other treatment technologies are present, calculate the average removal (by CEC), identify the minimum and maximum percent removal from the data set, tally the number of treatment systems included in the average, and provide the reference identification numbers for studies which include data.
  - — For example, if the user selects denitrification (DEN)
    - ▪ ...the following systems WILL be included in the average:
      - • System A – ASL, NT, DEN, CL, RO
      - • System B – MBR, NT, DEN, OZN, RO
    - ▪ …the following systems WILL NOT be included in the average:
      - • System C – ASL, NT, OZ
      - • System D – ASL, GAC, McF, OZN
    - ▪ …NO isolated unit processes will be included in the average. In other words, NONE of the following unit processes would be included in the average:
      - • Unit A – DEN
      - • Unit B – ASL

- If you select TWO treatment technologies, you must indicate if ALL or AT LEAST ONE of the treatment technologies must be present in a system to be included in the average removals.
  - — For example, if you select activated sludge (ASL) AND chlorine disinfection (CL) and ALL:
    - ▪ ...the following systems WILL be included in the average:
      - • System A – ASL, CP, RO, CL
      - • System B – ST, ASL, CL
      - • System C – ASL, NT, DEN, CL, RO
    - ▪ ...the following systems WILL NOT be included in the average:
      - • System D – ASL, NT, OZN (because it has ASL but not CL)
      - • System E – MBR, McF, CL (because it has CL but not ASL)
  - — For example, if the user selects activated sludge (ASL) AND chlorine disinfection (CL) and AT LEAST ONE:
    - ▪ the following systems WILL be included in the average:
      - • System A – ASL, CP, RO, CL
      - • System B – ST, ASL, CL
      - • System C – ASL, NT, DEN, CL, RO
      - • System D – ASL, NT, OZN
      - • System E – MBR, McF, CL

EXAMPLES USING THE UNIT PROCESS OPTION

- Using the unit process option, the database will calculate removal averages using all studies that isolate the selected treatment technology.

- You can only select one treatment technology at a time. When you select a treatment technology, the database will identify all studies that isolate the performance of that treatment technology, calculate the average removal (by CEC), identify minimum and maximum percent removal from the data set, tally the number of studies included in the average, and provide the reference identification numbers for studies which include data.
  - For example, if the user selects denitrification (DEN)
    - ...the following units WILL be included in the average:
      - Unit A – DEN
      - Unit B – DEN
    - ...the following units WILL NOT be included in the average:
      - Unit A – ASL
      - Unit B – CL
    - …NO systems will be included in the average. In other words, NONE of the following systems would be included in the average:
      - System C – ASL, DEN, OZN
      - System D – ASL, GAC, DEN, OZN

Appendix C

CECS REMOVALS DATABASE BIBLIOGRAPHY

Table C-1. Literature Review Bibliography

ID	Authors	Date	Title	Journal/Publisher	Volume/Pages	Geographic Scope	Scale	Abstract
5	Anderson, Henrik; Hansruedi Siegrist; Bent Halling-Sorensen; Thomas A. Ternes	2003	Fate of Estrogens in a Municipal Sewage Treatment Plant	Environmental Science & Technology (journal) and American Chemical Society (publisher)	37:4021-4026	Europe	full	The main outcome of this study was that a common municipal STP with an activated sludge system for nitrification and denitrification including sludge recirculation can appreciably eliminate natural and synthetic estrogens. In the effluent, estrogen levels were always below the detection limit of 1 ng/l. A mass balance shows that the natural estrogens were largely degraded biologically in the nitrification/denitrification steps, while only a small percentage physically sorbed onto digested sewage sludge. An essential conclusion of this paper is the comparison made before and after nitrification/denitrification process steps were added to the plant. Ten years ago, the plant consisted only of a conventional activated sludge system and the effluent concentrations were many times higher than those found in this study.
20	Carballa, M; F. Omil; JM Lema; M Llompart; C Garcia-Jares; I Rodriguez; M Gomez; T Ternes	2004	Behavior of pharmaceuticals, cosmetics and hormones in a sewage treatment plant	Water Research (journal) and Elsevier (publisher)	38:2918-2926	Europe	full	A sewage treatment plant in Spain was studied to examine the treatment effectiveness on several cosmetic ingredients, pharmaceuticals, and hormones. Influent to the STP was tested as well as after each step of the treatment system. The results were examined to determine what types of treatment are most effective for each class of compounds. The overall removal efficiencies within the STP ranged between 70-90% for fragrances, 40-65% for anti-inflammatories, around 65% for 17b-estradiol, and 60% for sulfamethoxazole.The concentration of estrone increased along the treatment due to partial oxidation of 17b-estradiol in the aeration tank.
70	Clara, M.; N. Kreuzinger; B. Strenn; O. Gans; and H. Kroiss	2005	The solids retention time--a suitable design parameter to evaluate the capacity of wastewater treatment plants to remove micropollutants	Water Research (journal) and Elsevier (publisher)	39: 97-106	Europe	full, pilot	Nine systems, including six full-scale activated sludge WWTPs with varying SRTs and three MBR pilot systems with varying SRTs, were sampled in Europe for PPCP, S/H, and NP/APEs analytes. Bis-A, ibuprofen, bezafibrate, and the natural estrogens show a strong correlation between effluent concentration and SRT. Carbamazepine was not affected during treatment. Only analytes showed contradictory results. The results of the investigations lead to the conclusion that low effluent concentrations can be achieved in WWTPs operating SRTs higher than 10 days. The results came from the POSEIDON Project.

Table C-1. Literature Review Bibliography (Continued)

ID	Authors	Date	Title	Journal/Publisher	Volume/Pages	Geographic Scope	Scale	Abstract
93	Stephenson, Roger and Joan Oppenheimer	2007	Fate of Pharmaceuticals and Personal Care Products through Municipal Wastewater Treatment Processes	Water Environment Resources Foundation (WERF) and IWA Publishing	124	U.S.	full, pilot	Data were collected to measure the removal of 20 PPCPs commonly found in the influent of six full-scale wastewater treatment facilities operating in the U.S. The plants employed varying combinations of treatment operations, including: activated sludge, media filtration, chlorine disinfection, ultraviolet disinfection, and reverse osmosis. It was observed that an increase in SRT enhanced the removal of a majority of the PPCPs. The removal is compound-specific, but typically responds 80% or higher at SRTs of 5-15 days. Caffeine, ibuprofen, oxybenzone, chloroxylenol methylparaben, Benzyl salicylate, 3-Phenylpropionate butylbenzyl phthalate, and Octylmethoxycinnamate were among those compounds detected frequently with good removal. BHA, DEET, musk keton, and galozide were detected frequently and had poor removals.
94	Drewes, Jorg E.; Joceyln D.C. Hemming; James J. Schauer; and William C. Sonzogni	2008	Removal of Endocrine Disrupting Compounds in Water Reclamation Processes	Water Environment Resources Foundation (WERF) and IWA Publishing	180	U.S.	full	This study was conducted to develop approaches combining bioassays with chemical analysis to study removal of endocrine disrupting compounds by water reclamation treatment processes. Eleven treatment plants were sampled in the U.S. for S/H and NP/APEs analytes. The plants employed varying combinations of treatment operations, including: activated sludge, media filtration, chlorine disinfection, ultraviolet disinfection, reverse osmosis, membrane bioreactors, and soil-aquifer technology (SAT). The study provides information about the influent characteristics (percent of domestic versus industrial) and the sludge retention time at each plant. Plants with high BOD had higher concentrations of EDCs, and high BOD removal also correlated to high EDC removal. Advanced treatment processes: activated carbon, membranes, and SAT removed many EDCs to below detection limits.
95	Snyder, Shane A.; Samer Adham; Adam M. Redding; Fred S. Cannon; James DeCarolis; Joan Oppenheimer; Eric C. Wert; and Yeomin Yoon	2007	Role of Membranes and Activated Carbon in the Removal of Endocrine Disruptors and Pharmaceuticals	Desalination (journal) and Elsevier (publisher)	202, 1-3: 156-181	U.S.	full	This study was conducted to provide a comprehensive evaluation of the efficacy of a variety of viable membrane and carbon processes to reduce the concentration of emerging contaminants in water. Four systems (two full-scale RO water reuse systems with intermediate treatment steps and two granular activated carbon water reuse facilities) were sampled in the U.S. for PPCP, S/H, and pesticide analytes. MF and UF membranes have little removal value for a majority of organic contaminants, but they have potential for removal of S/H, especially when operated as an MBR. RO membranes are capable of removing nearly all compounds investigated to levels less than reporting limits (a multi-barrier approach, double-pass is best for removal). PAC and GAC were capable of removing nearly all compounds evaluated by greater than 90%.

Table C-1. Literature Review Bibliography (Continued)

ID	Authors	Date	Title	Journal/Publisher	Volume/Pages	Geographic Scope	Scale	Abstract
96	Snyder, Shane A.; Eric C. Wert; Hongxia (Dawn) Lei; Paul Westerhoff; Yeomin Yoon	2007	Removal of EDCs and Pharmaceuticals in Drinking and Reuse Treatment Processes	AWWA Research Foundation		U.S.	full, lab, pilot	Samples were collected during various stages of treatment at 86 lab/bench experiments, 69 pilot plants, and 43 full scale plants employing a variety of treatment technologies, including: coagulation/flocculation/softening, activated carbon, chlorine oxidation, ozone and hydrogen peroxide, ultraviolet light, membranes, magnetic ion-exchange, and other biological processes. The results suggested the following: 1) Several target analytes were detected in raw and finishing drinking waters across the US. 2) Coagulation/flocculation/softening, UV irradiation (not high energy), exhausted activated carbon, magnetic-ion exchange, ultrafiltration, and microfiltration are ineffective for removing a majority of EDCs and PPCPs. 3) Free chlorine disinfection can remova many target compounds depending on their structure. 4) Chloramines are less effective than free chlorine at EDC/PPCP removal.5) Ozone is much more effective than chlorine. 6) Ozone, high energy UV at oxidative doses, advanced oxidative processes (ozone/peroxide, UV/peroxide), activated carbon, reverse osmosis, and nanofiltration are highly effective at removing EDCs/PPCPs. 7) Treatment trains combining advanced processes are the most effective for removals. 8) Biological removal and sorption processes can reduce concentrations.
97	Yu, Jim T.; Edward J. Bouwer; Mehmet Coelhan	2006	Occurrence and biodegradability studies of selected pharmaceuticals and personal care products in sewage effluent	Agricultural Water Management (journal) and Elsevier (publisher)	86: 72-80	U.S.	full	18 PPCPs were sampled for at a local wastewater treatment plant. 16 of the 18 PPCPs, which span a range of therapeutic classes and some commonly used personal care products, were detected at the influent to the Baltimore Back River WWTP in MD.10 of the 18 were detected in the effluent, signifying incomplete removal during treatment. The occurrence studies show that PPCPs are present in WWTP influent. A batch biodegradability study, done along side the sampling episode, suggests that biotransformation is a possible removal mechanism for PPCPs during groundwater recharge or soil aquifer treatment.
98	Lishman, Lori; Shirley Anne Smyth; Kurtis Sarafin; Sonya Kleywegt; John Toito; Thomas Peart; Bill Lee; Mark Servos; Michel Beland; Peter Seto	2006	Occurrence and reductions of pharmaceuticals and personal care products and estrogens by municipal wastewater treatment plants in Ontario, Canada	Science of the Total Environment (journal) and Elsevier (publisher)	367: 544-558	Canada	full	The purpose of this study was to expand/establish a Canadian database for the presence of selected acidic drugs, triclosan, polycyclic musks, and selected estrogens in MWWTP influent and effluent. Twelve WWTPs were samples with lagoons, conventional activated sludge (CAS), and CAS with media filtration. Wastewater sources (domestic, commercial, industrial) and SRTs were given for each plant. Ibuprofen and naproxen had consistently high reductions. Ketoprofen and indomethacin were removed about 23-44%. Gemfibrozil and diclofenac had median reductions of 66% and -34%. More removals were seen of these compounds with SRTs over 30 days. Triclosan reductions ranged from 74-98%; lagoons systems appeared to be the best treatment for triclosan. Musks were removed 98-99% in lagoon systems and 37-65% in CAS systems. E1 and E2 hormones were rarely detected in the effluent.

Table C-1. Literature Review Bibliography (Continued)

ID	Authors	Date	Title	Journal/Publisher	Volume/Pages	Geographic Scope	Scale	Abstract
99	Batt, Angela L.; Sungpyo Kim, Diana S. Aga	2007	Comparison of the occurrence of antibiotics in four full-scale wastewater treatment plants with varying designs and operations	Chemosphere (journal) and Elsevier (publisher)	68: 428-435	U.S.	full	The occurrence of ciprofloxacin, sulfamethoxazole, tetracycline, and trimethoprime antibiotics in four full-scale WWTPs that differ in design and operating conditions were determined. Treatment included: two stage activated sludge process with nitrification tank, extended aeration, RBCs, and pure oxygen activated sludge. Some employed chlorination or UV. Removals ranged from 33-97%. Removal is dependent on operating conditions of the treatment system and the treatment processes. UV radiation did not appear to reduce concentration of antibiotics, but chemical degradation via chlorine disinfection can contribute to the removal of antibiotics. SRT is an important parameter affecting removals.
100	Clara, M.; B. Strenn; O. Gans; E. Martinez; N. Kreuzinger; and H. Kroiss	2005	Removal of selected pharmaceuticals, fragrances and endocrine disrupting compounds in a membrane bioreactor and conventional wastewater treatment plants	Water Research (journal) and Elsevier (publisher)	39: 4797-4807	Europe	full, pilot	Eight pharmaceuticals, two polycyclic musk fragrances, and nine EDCs were analyzed in 3 WWTPs with activated sludge treatment and varying loading conditions. Three pilot MBRs were operated at different SRTs. Carbamazepine was not removed in any of the sampled treatment facilities. BPA, ibuprofen, and bezafibrate were nearly completely removed (>90%). SRTs suitable for nitrogen removals (SRT > 10 days) increase the removal of selected micropollutants. NP/APEs were removed in high extend in very low-loaded conventional WWTPs.
101	Boyd, G.; H. Reemtsma; D. Grim; and S. Mitra	2003	Pharmaceuticals and personal care products (PPCPs) in surface and treated waters of Louisiana, USA and Ontario, Canada	The Science of the Total Environment (journal) and Elsevier (publisher)	311: 135-149	U.S., Canada	full, pilot	Samples taken from the effluents of water treatment plants in Ontario and Louisiana were analyzed for nine PPCP's using GC/MS. These concentrations were compared to that of the influents from the Detroit and Mississippi Rivers. Chlorination, ozonation and dual media filtration reduced the concentration of naproxen and clofibric acid below GC/MS detection levels. Continuous addition of activated carbon in conjunction with conventional drinking water treatment processes (coagulation, sedimentation and flocculation) failed to reduce naproxen levels in samples taken from the Mississippi River.
102	Drewes, Jorg E., Martin Reinhard, Peter Fox	2003	Comparing Microfiltration-reverse Osmosis and Soil-aquifer Treatment for Indirect Potable Reuse of Water	Water Research (journal) and Elsevier (publisher)	37:3612-3621	U.S.	full, pilot	This study was conducted at a water reclaimation plant in Arizona. The study evaluated organics removal from treated tertiary effluent in pilot scale studies by microfiltration and reverse osmosis or nanofiltration and in full scale studies by soil-aquifer treatment. SAT and microfiltration plus reverse osmosis or nanofiltration effectively treated the emerging contaminants studied.
103	Huntsman, Brent E., Charles A. Staples, Carter G. Naylor, Jim-Bob Williams	2006	Treatability of Nonylphenol Ethoxylate Surfactants in On-Site Wastewater Disposal Systems	Water Environment Research	78:2397-2404	U.S.	full	This two year study was conducted to evaluate the fate of nonylphenol ethoxylates (NPEs) discharged to a residential wastewater disposal (septic) system. NPE-based detergents were metered into a full scale septic system associated with a single-family household and soil pore water and groundwater samples were collected at various locations in the disposal system. The data show that elimination of NPE surfactants within an on-site disposal system is both relatively rapid and complete.

Table C-1. Literature Review Bibliography (Continued)

ID	Authors	Date	Title	Journal/Publisher	Volume/Pages	Geographic Scope	Scale	Abstract
105	Stackelberg, Paul E.; Jacob Gibbs; Edward T. Furlong; Michael T. Meyer; Steven D. Zaugg; R. Lee Lippincott	2007	Efficiency of Conventional Drinking-water-treatment Processes in Removal of Pharmaceuticals and Other Organic Compounds	The Science of the Total Environment (journal) and Elsevier (publisher)	377:255-272	U.S.	full	Samples of water from a coventional drinking water treatment plant were analyzed for 113 organic compounds that included pharmaceuticals, detergents, flame retardants, PAHs, fragrances, flavorants, pesticides, and steroids. The average percent removal was calculated for each compound following clarification, disinfection, and GAC filtration. In general, GAC filtration accounted for 53% removal, disinfection accounted for 32%, and clarification accounted for 15%. Substantial but incomplete degradation or removal of OCs occurred at this plant.
106	Al-Rifai, Jawad H.; Gabefish, Candace L.; Schaefer, Andrea I.	2007	Occurrence of pharmaceutically active and non-steroidal estrogenic compounds in three different wastewater recycling schemes in Australia	Chemosphere (journal) and Elsevier (publisher)	69: 801-815	Other	full	Three Australian wastewater recycling schemes were studied for their effectiveness to remove trace organic contaminents including pharmaceuticals and non-steroidal estrogenic compounds. The schemes included RO and carbon filration.
107	Gobel, Anke; Christa S. McArdell; Adriano Joss; Hansruedi Siegrist; Walter Giger	2007	Fate of Sulfonamides, Macrolides, and Trimethoprim in Different Wastewater Treatment Technologies	The Science of the Total Environment (journal) and Elsevier (publisher)	372:361-371	Europe	full	The elimination of sulfonamides, macrolides, and trimethoprim from raw wastewater was investigated in two wastewater treatment plants (both with two trains). Primary treatment provided no significant eliminations and secondary treatment observed for two conventional activated sludge systems and a fixed bed reactor showed little to no significant elimination.
108	Hashimoto, T.; Onda, K.; Nakamura, Y.; Tada, K.; Miya, A.; Murakami, T.	2007	Comparison of natural estrogen removal efficiency in the conventional activated sludge process and the oxidation ditch process	Water Research (journal) and Elsevier (publisher)	41: 2117-2126	Other	full	This study was conducted to investigate the behavior of natural estrogens in twenty full scale WWTPs in Japan, and the difference of natural estrogen removal efficiency between CAS plants and OD plants were evaluated.
109	Nakada, Norihide; Hiroyuki Shinohara; Ayako Murata; Kentaro Kiri; Satoshi Managaki; Nobuyuki Sato; Hideshige Takada	2007	Removal of selected pharmaceuticals and personal care products (PPCPs) and endocrine-disrupting chemicals (EDCs) during sand filtration and ozonation at a municipal sewage treatment plant	Water Research (journal) and Elsevier (publisher)	41:4273-4382	Other	full	The article studies the removal efficiencies of 24 pharmaceutically active compounds during activated sludge treatment, sand filtration and ozonation in an operating municipal sewage treatment plant. The combination of sand filtration and ozonation showed a greater than 80% removal of 22 of most of the target compounds.
110	Roslev, Peter; Vorkamp, Katrin; Aarup, Jakob; Frederiksen, Klaus; Nielsen, Per Halkjoer	2007	Degradation of phthalate esters in an activated sludge wastewater treatment plant	Water Research (journal) and Elsevier (publisher)	41: 969-976	Europe	full	This study, sponsored by the Danish Technical Research Council, was conducted to investigate the fate of DMP, DBP, BBP and DEHP in a full scale activated sludge WWTP with biological removal of nitrogen.
112	Thomas, Paul; Gregory Foster	2005	Tracking Acidic Pharmaceuticals, Caffeine, and Triclosan through the Wastewater Treatment Process	Environmental Toxicology and Chemistry (journal) and SETAC Press (publisher)	24:25-30	U.S.	full	The purpose of this study was to determine which stage of conventional wastewater treatment is most effective at removing several acidic pharmaceuticals, caffeine and troclosan. The results show that secondary treatment was the most effective treatment step, removing 51-99 percent of the compounds under study from the influent.
113	Vogelsang, C.; Grung, M.; Jantsch, T. G.; Tollefsen, K. E.; and H. Liltved	2006	Occurrence and removal of selected organic micropollutants at mechanical, chemical and advanced wastewater treatment plants in Norway	Norwegian Institute for Water Research (journal) and Elsevier (publisher)	40; 3359-3570	Europe	full	Five waste water treatment plants in Norway were compared in their ability to remove organic micropollutants. The plants employed combinations of mechanical (sand media filtration), chemical (coagulation) and biological (sludge) treatments. The best results were obtained by a combination biological and chemical treatments.

Table C-1. Literature Review Bibliography (Continued)

ID	Authors	Date	Title	Journal/Publisher	Volume/Pages	Geographic Scope	Scale	Abstract
238	Soliman, Mary A.; Joel A. Pedersen; Heesu Park; Angelica Castaneda-Jimenez; Michael K. Stenstrom; I. H. (Mel) Suffet	2007	Human pharmaceuticals, antioxidants, and plasticizers in wastewater treatment plant and water reclamation plant effluents	Water Environment Research (journal)	79:156-167	U.S.	full, pilot	The primary objective of this study was to determine the presence of unregulated organic chemicals in reclaimed water using complimentary targeted and broad spectrum approaches. The removal of the compounds by three different tertiary treatment trains at a wastewater treatment plant and two water reclamation facilities was studied. The lime/RO product waters contained lower concentrations of clofibric acid, ibuprofen, caffeine, BHA, and N-BBSA than California Title 22 water. The MF/RO treatmen reduced concentrations to levels below their detection limits.
240	Stasinakis, Athanasios S.; Anastasios V. Petalas; Daniel Mamais; Nikolaos S. Thomaidis; Georgia Gatidou; Themistokles D. Lekkas	2007	Investigation of triclosan fate and toxicity in continuous-flow activated sludge systems	Chemosphere (journal) and Elsevier (publisher)	68:375-381	Europe	lab	The purpose of this research was to study the fate and toxicity of triclosan (TCS) in activated sludge systems and to investigate the role of biodegradation and sorption on its removal. Two continuous-flow activated sludge systems were used; one system was used as a control, while the other received TCS concentrations equal to 0.5 and 2 mg l/1. At the end of the experiment, 1 mg l/1 TCS was added in the control system to investigate TCS behaviour and effects on non-acclimatized biomass. For all concentrations tested, more than 90% of the added TCS was removed during the activated sludge process. Determination of TCS in the dissolved and particulate phase and calculation of its mass flux revealed that TCS was mainly biodegraded. Activated sludge ability to biodegrade TCS depended on biomass acclimatization and resulted in a mean biodegradation of 97%. Experiments with batch and continuous-flow systems revealed that TCS is rapidly sorbed on the suspended solids and afterwards, direct biodegradation of sorbed TCS is performed. Regarding TCS effects on activated sludge process, addition of 0.5 mg/l TCS on non-acclimatized biomass initially deteriorated ammonia removal and nitrification capacity. After acclimatization of biomass, nitrification was fully recovered and further increase of TCS to 2 mg/l did not affect the performance of activated sludge system. The effect of TCS on organic substrate removal was minor for concentrations up to 2 mg/l,indicating that heterotrophic microorganisms are less sensitive to TCS than nitrifiers.
243	Vieno, N.; T. Tuhkanen; L. Kronberg	2007	Elimination of pharmaceuticals in sewage treatment plants in Finland	Water Research (journal) and Elsevier (publisher)	41:1001-1012	Europe	full	The occurrence of eight pharmaceuticals (b-blockers: acebutolol, atenolol, metoprolol and sotalol; antiepileptic: carbamazepine; fluoroquinolone antibiotics: ciprofloxacin, norfloxacin, ofloxacin) were assessed in the raw and treated sewage of 12 sewage treatment plants (STPs) in Finland. The work shows that especially carbamazepine and the b-blockers may reach the recipient waters and there is a need to enhance their elimination in the sewage treatment plants. In this attempt, a denitrifying biofilter as a tertiary treatment could be of minor importance since in this study it did not result in further elimination of the target compounds.

Table C-1. Literature Review Bibliography (Continued)

ID	Authors	Date	Title	Journal/Publisher	Volume/Pages	Geographic Scope	Scale	Abstract
244	Weber S; M. Gallenkemper; T. Melin; W; Dott; J. Hollender	2004	Efficiency of nanofiltration for the elimination of steroids from water	Water Science and Technology (journal) and IWA Publishing (publisher)	50:9-14	Europe	lab	The elimination of natural and synthetic steroids by nanofiltration using a laboratory membrane reactor was investigated. Chemical analysis of 17-β-estradiol, estrone, estriol, 17-α-ethinylestradiol, mestranol, diethylstilbestrol, progesterone and β-sitosterine was performed after solid phase extraction by GC-MS with standard addition. The elimination rate depended on the nanofiltration membrane material. LFC1 membrane consisting of polyamide removed the steroids over 99% whereas PES10 membrane consisting of hydrolysed polyethersulfone was less efficient, obviously caused by different pore sizes and permeability of the membrane structure.
245	Westerhoff, Paul; Yeomin Yoon; Shane Snyder; Eric Wert	2005	Fate of Endocrine-Disruptor, Pharmaceutical, and Personal Care Product Chemicals during Simulated Drinking Water Treatement Processes	Environmental Science and Technology (journal) and American Chemical Society (publisher)	39:6649-6663	U.S.	lab	The objective of this study was to compare the removals of PAH/EDC/PPCPs spiked at environmentally relevant concentrations into three natural waters or a model water by adsorptive processes (coagulation, softening, PAC addition) and oxidative processes (chlorine, ozone) under conditions (doses, contact times) practices in drinking water treatment plants. Aluminum sulfate and ferric chloride coagulants or chemical lime softening removed some PAHs but removed <25 percent of PPCPs and EDCs. Activated carbon removals ranged from 10 to >98 percent. Separate chlorine and ozone experiments removals (reported as percent reacted) ranged from <10 to >90 percent.
248	Zhang, Heqing; Harumi Yamada; Sung-Eun Kim; Hyo-Sang Kim; Hiroshi Tsuno	2006	Removal of endocrine-disrupting chemicals by ozonation in sewage treatment	Water Science and Technology (journal) and IWA Publishing (publisher)	54:123-132	Other	full	Two laboratory scale semi-batch ozonation experiments and a full scale ozonation process were evaluated in their ability to remove estrogens and minimize the production of brominated byproducts. Results show that ozonation can remove estrogens from the influent. The authors propose ideal ozone concentrations with respect to DOC concentrations to minimize brominated byproducts.
277	Bester, K.	2003	Triclosan in a sewage treatment process - balances and monitoring data	Water Research (journal) and Elsevier (publisher)	37:3891-3896	Europe	full	In a German sewage treatment plant, the concentrations of triclosan in the influent (1000 ng/L) as well as in the effluent (50 ng/L) are compared to the concentrations measured in sludge (1200 ng/L). Considering the mass flow of water and sludge in the respective plant, balances including water and sludge are calculated. Thirty percent of the triclosan is sorbed with weak bonds to the sludge, while some amounts are sorbed as bound residues in the sludge. About 5% is dissolved in the out-flowing water. Thus most of the influent triclosan is likely transformed to other metabolites or unrecovered bound residues. Removal was greater than 90% while about 30% sorbed to the sludge.
288	Carucci, Alessandra; Giovanna Cappai; Martina Piredda	2006	Biodegradability and Toxicity of Pharmaceuticals in Biological Wastewater Treatment Plants	Journal of Environmental Science and Health Part A (journal) and Taylor and Francis Group (publisher)	41:1831-1842	Europe	lab	Municipal wastewater was fed to laboratory scale SBR (Sequencing Batch Reactor) operated with different sludge ages (8 and 14 days), different biochemical conditions (aerobic or anoxic-aerobic mode) and several influent drug concentrations (2, 3 and 5 mg/L). Comparison of results with a previous study shows that the percent removal of atenolol in municipal wastewater (36%) was lower than the removal in synthetic wastewater (up to 90%). Adsorption batch tests showed that a major mechanism of removal for atenolol was adsorption. In contrast, adsorption did not contribute to the removal of ranitidine.

Table C-1. Literature Review Bibliography (Continued)

ID	Authors	Date	Title	Journal/Publisher	Volume/Pages	Geographic Scope	Scale	Abstract
292	Chen, Chia-Yang; Tzu-Yao Wen; Gen-Shuh Wang; Hui-Wen Cheng; Ying-Hsuan Lin; Guang-Wen Lien	2007	Determining estrogenic steroids in Taipei waters and removal in drinking water treatment using high-flow solid-phase extraction and liquid chromatography/tandem mass spectrometry	Science of the Total Environment (journal) Elsevier (publisher)	378:352-365	Other	lab	River water and wastewater treatment plant (WWTP) effluents from metropolitan Taipei, Taiwan were tested for the presence of the pollutants estrone (E1), estriol (E3), 17β-estradiol (E2), and 17α-ethinylestradiol (EE2) using a new methodology that involves high-flow solid-phase extraction and liquid chromatography/tandemmass spectrometry. The method was also used to investigate the removal of the analytes by conventional drinking water treatment processes. Rapid filtration, with crushed anthracite played a major role, removing more than 84% of the estrogens. Except for E3, the whole procedure successfully removed most of the estrogens even if the initial concentration reached levels as high as 500 ng/L.
298	Choi, Keun-Joo; Sang Goo Kim; Chang Won Kim; Jae Kwang Park	2006	Removal efficiences of endocrine disrupting chemicals by coagulation/flocculation, ozonation, powdered/granular activated carbon adsorption, and chlorination	Korean Journal of Chemical Engineering (journal)	23:399-408	Other	lab	Removal efficiencies of endocrine disruptors (bisphenol A and nonylphenol) were evaluated using various types of water treatment processes in lab and pilot scale studies. Paired removal data reported tests various coagulants. The conventional coagulation/flocculation water treatment process had very low removal efficiencies for BPA (0-3%) and nonylphenol (4-7%).
304	Comerton, Anna M.; Robert C. Andrews; David M. Bagley; Paul Yang	2007	Membrane adsorption of endocrine disrupting compounds and pharmaceutically active compounds	Journal of Membrane Science (journal) and Elsevier (publisher)	303:267-277	Canada	lab	Adsorption is one of the main mechanisms contributing to compound removal by membrane filtration, in addition to size exclusion and charge repulsion. In this study, the adsorption of 22 endocrine disrupting compounds and pharmaceutically active compounds by ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) membranes was investigated using 24-h bottle tests at 21 and 4 ◦C. Two natural waters (Lake Ontario and effluent from a membrane bioreactor (MBR)) and one laboratory-grade water were examined. Adsorption was strongly correlated with compound log Kow and membrane pure water permeability, and moderately correlated with compound water solubility. Adsorption was observed to be highest by the UF membrane followed by the NF and RO membranes. The influence of temperature on adsorption in the range examined was found to be insignificant. Three compounds for which deuterium-labelled surrogates were available (acetaminophen, carbamazepine, gemfibrozil) were examined to determine the influence of water matrix on adsorption. Adsorption of gemfibrozil may have been hindered due to competition for adsorption sites from the organic matter present in the lake water and MBR effluent.
319	Ermawati, Rahyani; Shigeru Morimura; Yueqin Tang; Kai Liu; Kenji Kida	2007	Degradation and Behaviour of Natural Steroid Hormones in Cow Manure Waste during Biological Treatments and Ozone Oxidation	Journal of Bioscience and Bioengineering (journal) and The Society for Biotechnology, Japan (publisher)	103:27-31	Other	lab	The article reserached an efficient treatment process for screened cow manure waste for the degradation of natural steroid hormones. The manure was diluted with tap water with aerobic, anaerobic treatment and ozone oxidation to measure reduction of classical pollutants and natural hormones at 99%.

Table C-1. Literature Review Bibliography (Continued)

ID	Authors	Date	Title	Journal/Publisher	Volume/Pages	Geographic Scope	Scale	Abstract
320	Escher, Beate I; Wouter Pronk; Mark JF Suter; Max Maurer	2006	Monitoring the removal efficiency of pharmaceuticals and hormones in different treatment processes of source-separated urine with bioassays	Environmental Science Technology (journal) and American Chemical Society (publisher)	40:5095-5101	Europe	lab	Urine treatment technologies were evaluated for their performance to remove micorpollutants such as pharmaceuticals, natural and synthetic steroid hormones, and their human biotransformation products. Removal efficiencies were determined with a combination of bioassays and chemical target analysis. Filtration methods, such as nanofiltration and electrodialysis, were highly efficient with respect to toxicity reduction. Micropollutant degradation during biological treatment in a sequencing batch reactor was very compound specific. Ozonation removed the target analytes and the estrogenicity completely.
333	Gebhardt, Wilhelm; Horst Fr. Schoerder	2007	Liquid chromatography-(tandem) mass spectrometry for the follow-up of the elimination of persistent pharmaceuticals during wastewater treatment applying biological wastewater treatment and advanced oxidation	Journal of Chromatography A (journal) and Elsevier (publisher)	1160:34-43	Europe	lab	Advanced oxidation methods using ozone, ozone with UV, and hydrogen peroxide treatment with UV was studied to evaluate the elimination of pharmaceutical compounds carbamazepine, diazepam, clofibric acid, and diclofenac. While biological treatment by conventional and membrane bioreactors failed, the advanced oxidation methods using ozone, O3/UV, or hydrogen peroxide/UV successfully led to the complete elimination of these compounds. Target compounds could be confirmed as permanently present pollutants in Aachen-Soers wastewater in concentrations between 0.006 and 1.9 ug/L.
337	Gómez, M.; G. Garralón; F. Plaza; R. Vílchez; E. Hontoria; M. A. Gómez	2007	Rejection of endocrine disrupting compounds (bisphenol A, bisphenol F and triethyleneglycol dimethacrylate) by membrane technologies	Desalination (journal) and Elsevier (publisher)	212: 79-91	Europe	lab	This study examined the effectiveness of ultrafiltration, microfiltration and reverse osmosis membranes in removing three compounds. The system was fed with treated effluent from a municipal wastewater treatment plant and spiked with high levels (single-digit mg/L) of bisphenol-A, bisphenol-F and triethylene glycol dimethacrylate. Micro- and ultrafiltration demonstrated a certain effectiveness in removing all three compounds, owing to their association with particulate matter which is retained by these treatments. In all cases, high concentrations of the assayed endocrine disruptors were still found in the treated effluents, casting doubt on the suitability of membrane technologies when the concentrations of these compounds in the influent are high.
338	Gonzalez, Susana; Jutta Muller; Mira Petrovic; Damia Barcelo; Thomas P. Knepper	2006	Biodegradation studies of selected priority acidic pesticides and diclofenac in different bioreactors	Environmental Pollution (journal) and Elsevier (publisher)	144:926-932	Europe	pilot	The biodegradation of selected priority acidic pesticides MCPP, MCPA, 2,4-D, 2,4-DP and bentazone and the acidic pharmaceutical diclofenac was investigated using a membrane bioreactor (MBR) and a fixed-bed bioreactor (FBBR). A pilot plant MBR was fed with raw water spiked with the selected compounds. The experiment was repeated every week during four weeks to enhance the adaptation of microorganisms. In order to further study the biodegradability of these compounds, degradation studies in a FBBR were carried out.The results indicate that in the MBR compounds except for bentazone were eliminated within the first day of the experiment at rates ranging from 44% to 85%. Comparing these results with the degradation rates in the FBBR showed that in the latter only MCPP, MCPA 2,4-D and 2,4-DP were degraded after a much longer adaptation phase of microorganisms.

Table C-1. Literature Review Bibliography (Continued)

ID	Authors	Date	Title	Journal/Publisher	Volume/Pages	Geographic Scope	Scale	Abstract
346	Heidler, Jochen; Amir Sapkota; Rolf Halden	2006	Partitioning, Persistence, and Accumulation in Digested Sludge of the Topical Antiseptic Triclocarban during Wastewater Treatment	Environmental Science Technology (journal) and American Chemical Society (publisher)	40: 3634–3639	U.S.	full	This study explored the persistence of triclocarban in a typical full-scale activated sludge sewage treatment plant using a mass balance approach. Fluctuations of triclocarban concentration in the influent and effluent and flow rate were observed over various time scales (both a 24 hour period and 7 days). The removal calculated from the average concentration in the influent and effluent was 97 +/- 1%. Due to strong sorption of TCC to wastewater particulate matter (78 +/- 11% sorbed), the majority of the TCC mass was sequestered into sludge in the primary and secondary clarifiers of the plant. Anaerobic digestion for 19 days did not promote TCC transformation, resulting in an accumulation of the antiseptic compound in dewatered, digested municipal sludge to levels of 51 +/- 15 mg/kg dry weight (2815 +/- 917 g/d).
347	Heidler, Jochen; Rolf Halden	2007	Mass balance assessment of triclosan removal during conventional sewage treatment	Chemosphere (journal) and Elsevier (publisher)	66:362-369	U.S.	full	This study explored the persistence of triclosan in a typical full-scale activated sludge sewage treatment plant using a mass balance approach. Fluctuations of triclosan concentration in the influent and effluent and flow rate were observed over various time scales (both a 24 hour period and 7 days). The removal calculated from the average concentration in the influent and effluent was 98%. The mass balance revealed that 50% of the 98% remained detectable in the sludge while the remaining 48% was biotransformed or lost to other mechanisms of removal.
352	Horii, Yuichi; Jessica L. Reiner; Bommanna Loganathan; Kurunthachalam Senthil Kumar; Kenneth Sajwan; Kurunthachalam Kannan	2007	Occurrence and fate of polycyclic musks in wastewater treatment plants in Kentucky and Georgia, USA	Chemosphere (journal) and Elsevier (publisher)	68:2011-2020	U.S.	full	In this study, contamination profiles and mass flow of polycyclic musks (HHCB), (AHTN), and HHCB-lactone (oxidation product of HHCB), in two WWTPs, one located in Kentucky (Plant A, rural area) and the other in Georgia (Plant B, urban), USA, were determined. Mass balance analysis suggested that only 30% of HHCB and AHTN entering the plants was accounted for in the effluent and the sludge. Removal efficiencies of HHCB and AHTN in the two WWTPs ranged from 72% to 98%. In contrast, HHCB-lactone concentrations increased following the treatment.
359	Huo, C. X.; P. Hickey	2007	EDC Demonstration Programme in the UK - Anglian Water's Approach	Environmental Technology (journal) and Selper Ltd (publisher)	28:731-741	Europe	full	This study evaluated the sampling, preservation, and analysis technique and the concentrations of E1, E2, and EE2 in a typical trickling filter plant in the UK. Estrone removals were about 60% after humus tank and lagoon treatment while estradiol and ethinyl estradiol removals were about 90% and 50%, respectively.
366	Jin, X.; J.Y. Hu; M.L. Tint; S.L. Ong; Y. Biryulin; G. Polotskaya	2007	Estrogenic compounds removal by fullerene-containing membranes	Desalination (journal) and Elsevier (publisher)	214:83-90	Other	lab	This study examined new polymer membranes for the removal and adsorptive behaviours of estrogenic compounds. The removal, adsorption rate, and capacity of estrone by membranes with different fullerene compositions was studied. Removals were <95% for all membranes.
369	Kaping, Daniel; Hans-Dieter Stock; Kai Bester	2007	Pharmaceuticals in waste water treatment - Transformation products and possible effects in activated sludge treatment	Fresenius Environmental Bulletin (journal) and PSP (publisher)	16:1509-1516	Europe	lab	The transformation of selected pharmaceuticals in activated sludge treatment with advanced oxidation was analyzed. The possible side effects of the compounds on the sludge function was also studied. The concentrations of all pharmaceuticals at the effluents of ozonization and activated carbon filtration were below detection limits.

Table C-1. Literature Review Bibliography (Continued)

ID	Authors	Date	Title	Journal/Publisher	Volume/Pages	Geographic Scope	Scale	Abstract
379	Kim, Sang D.; Jaeweon Cho; In S. Kim; Brett J. Vanderford; Shane A.Snyder	2006	Occurrence and removal of pharmaceuticals and endocrine disruptors in South Korean surface, drinking, and waste waters	Water Research (journal) and Elsevier (publisher)	41:1013-1021	Other	full, pilot	The artcile used LC-MS/MS to measure the concentrations of 14 pharmaceuticals, 6 hormones, 2 antibiotics, 3 personal care products and 1 flame retardant in surface waters and wastewater treatment plant effluent in South Korea. Wastewater treatment processes at full and pilot-scale were both investigated. The analytes o fthe greatest concentration were iopromide, TCEP, sulfamethoxazole, and carbamazepine. However, the primary estrogen hormones, were rarely detected, while estrone was detected in oth surface water and wastewater effluent. Conventional drinking water treatment methods were relatively ineffiicent for contaminant removal, while efficient removal (~99%) was achieved by granular activated carbon (GAC). In wastewater treatment processes, membrane bioreactors (MBR) showed limited target compound removal, but were effective at eliminating hormones and some PPCPs. Membrane filtration using RO and NF showed excellent removal (>95%) for all target analytes.
384	Kreuzinger N; M. Clara; B. Strenn; B. Vogel	2004	Investigation on the behaviour of selected pharmaceuticals in the groundwater after infiltration of treated wastewater	Water Science and Technology (journal) and IWA Publishing (publisher)	50:221-228	Europe	full	In a rural arid area without suitable water, the treated wastewater of a low loaded municipal wastewater treatment plant with full nutrient removal and additional post treatment steps is infiltrated into the unsaturated soil for groundwater recharge. Grounwater probes placed at increasing distances were sampled over a period of 14 months as well as sampling around the wastewater treatment plant which was fed to the groudwater infiltration. Carbamazepine behaves very conservative and only is removed negligible even after long flow times within the subsurface zone. For other substances like diazepam or diclofenac, a partial elimination during the different steps of wastewater treatment can be ovserved. The musks were removed to some extent but not as good as the other compounds.

Table C-1. Literature Review Bibliography (Continued)

ID	Authors	Date	Title	Journal/Publisher	Volume/Pages	Geographic Scope	Scale	Abstract
392	Hongxia Lei, Shane A. Snyder	2007	3D QSPR models for the removal of trace organic contaminants by ozone and free chlorine	Water Research (journal) and Elsevier (publisher)	41:4051-4060	U.S.	pilot	Endocrine-disrupting compounds (EDCs) and pharmaceuticals and personal care products (PPCPs) have been detected at low levels in water resources around the world and one impact of their detection is the continuous concern on their fate and removal by various water treatment processes. In this research, a 3D quantitative structure–property relationship (QSPR) model characterized by the utilization of 3D molecular structures is explored as a potential tool to prescreen these compounds and help focus research on more persistent compounds during typical water treatment processes.The relevance of each parameter to removals of target compounds by ozone (O3) and free chlorine was determined based on data matrices generated in bench- and pilot-scale experiments. Calculated removals were correlated with experimental data with linear regression coefficients of 0.84 for ozonation and 0.71 for chlorination. The increased predictability of ozone removal reflects the fundamental simplicity of ozone reaction mechanisms, which is dominated by oxidation reactions. Interestingly, the weakly polar surface area, in addition to the p surface area of these molecules, seems critical to ozone removal. The removal of these compounds by free chlorine is related to their ozone removal ionization potential and three other parameters. The developed QSPR models help disclose the removal mechanism during ozonation and chlorination.
394	Leusch, Frederic D. L.; Heather F. Chapman; Michael R van den Heuvel; Benjamin L.L. Tan; S. Ravi Gooneratne; Louis A. Tremblay	2006	Bioassay-derived androgenic and estrogenic activity in municipal sewage in Australia and New Zealand	Ecotoxicology and Environmental Safety (journal) and Elsevier (publisher)	65:403-411	Other	full	Selected estrogenic chemicals were analyzed in raw sewage influent and subsequent treatment in three different types of treatment systems in 15 municipal sewage treatment plants in Australia and New Zealand. Secondary treatment was the most effective treatment of the estrogenic activity and 82% to >99% of the androgenic activity in sewage.
404	Majumder, Partha Sarathi; S.K. Gupta	2007	Removal of chlorophenols in sequential anaerobic-aerobic reactors	Bioresource Technology (journal) and Elsevier (publisher)	98:118-129	Other	lab	The combination of upflow anaerobic sludge blanket and aerobic rotating biological contactor reactors having higher biomass concentration and higher sludge retention time was applied for the sequential treatment of priority pollutant chlorophenol containing wastewater. Target compounds 2-CP and 2,4-DCP present in two simulated wastewaters at concentration of 30 mg/l each individually were sequentially treated in continuous mode by combined UASB-I, RBC-I and combined reactors. Optimum HRT combinations produced 2-CP and 2,4-DCP effluent having corresponding chlorophenol concentration of below detectable limit and 0.1 mg/l, respectively.

Table C-1. Literature Review Bibliography (Continued)

ID	Authors	Date	Title	Journal/Publisher	Volume/Pages	Geographic Scope	Scale	Abstract
435	Pauwels, Bram; Sam Deconinck; Willy Verstraete	2006	Electrolytic removal of 17 alpha-ethinylestradiol (EE2) in water streams	Journal of Chemical Technology and Biotechnology (journal) and Society of Chemical Industry (publisher)	81:1338-1343	Europe	lab	The electrolytic removal of ethinylestradiol (EE2) in effluent of a membrane bioreactor (MBR) treating hospital sewage and in drinking water, was studied at dosed concentrations of about 1mg EE2 L^{-1}. Removal efficiencies of up to 98% were obtained with supplemental efficient eradications of bacteria (up to 3.4 log units). Residual effects were observed when a treated flow was mixed with an untreated flow. An increasing concentration of NaCl resulted in an enhanced EE2 removal. This effect was more pronounced in MBR effluent than in drinking water. To approach more environmentally realistic concentrations, an experiment with initial concentration of 10 μg EE2 L^{-1} drinking water was set up, still resulting in an EE2 removal of 85%.
436	Peng, Xianzhi; Zhendi Wang; Wenxing Kuang; Jianhua Tan; Ken Li	2006	A preliminary study on the occurrence and behavior of sulfonamides, ofloxacin and chloramphenicol antimicrobials in wastewaters of two sewage treatment plants in Guangzhou, China	Science of the Total Environment (journal) and Elsevier (publisher)	371:314-322	Other	full	Wastewater samples were collected from two activated sludge sewage treatment plants in China. The concentrations of antimicrobials do not show substantial changes after preliminary mechnical sedimentation. No quantifiable sulfonamides and chloramphenicol have been identified, and >85% of ofloxacin has been removed in the effluents after activated sludge treatment, indicating that activated sludge treatment is effective to remove antimicrobial substances in municipal sludge.
444	Quintana, Jose Benito; Stefan Weiss; Thorsten Reemtsma	2005	Pathways and metabolites of microbial degradation of selected acidic pharmaceutical and their occurrence in municipal wastewater treated by a membrane bioreactor	Water Research (journal) and Elsevier (publisher)	39:2654-2664	Europe	lab	Laboratory degradation tests with 5 acidic pharmaceuticals using activated sludge as an unnocculum under aerobic condidtions were performed and microbial metabolites were tested. This data was bench scale performed on solid materials. A LC-MS method for the trace anaylsis of these metabolites in water was developed and applied to municipal wastewater. A membrane bioreactor was tested for removal capabilities.In the MBR tests, removals ranged from 23% (diclofenac) to 97% (ibuprofen). Municipal wastewater treatment by a MBR may gradually improve the removal of PPCPs.
445	Ramos M.S.; J.L. Davila; F. Esparza; F. Thalasso; J. Alba; A.L. Guerrero; F.J. Avelar	2005	Treatment of wastewater containing high phenol concentrations using stabilisation ponds enriched with activated sludge	Water Science and Technology (journal) and IWA Publishing (publisher)	51:257-260	Other	lab	Treatment of wastewater containing high phenol concentrations in laboratory-scale stabilisation ponds enriched with activated sludge was studied. Phenol was biodegraded efficiently, even when fed as the sole carbon source. The enriched ponds showed removal rates 1.8-20.5 times higher than the values obsrved in control pond (not enriched). The results suggest that enrichment is an effective method to increase xenobiotic removal rates of stabilisatio ponds.
456	Shappell, Nancy; Lloyd O. Billey; Dean forbes; Terry Matheny; Matthew E. Poach; Gudigopuram B. Reddy; Patrick G. Hunt	2007	Estrogenic Activity and Steroid Hormones in Swine Wastewater through a Lagoon Constructed-Wetland System	Environmental Science and Technology (journal) and American Chemical Society (publisher)	41:444-450	U.S.	full	The objectives of this experiment were to measure (1) the hormonal activity of the initial effluent and (2) the effectiveness of a lagoon-constructed wetland treatment system for producing an effluent with a low hormonal activity. Wetlands decreased estrogenic activity by 83-93%. Estrone was the most persistent estrogenic compound. Constructed wetlands produced effluents with estrogenic activity below the lowest equivalent E2 concentration known to have an effect on fish.

Table C-1. Literature Review Bibliography (Continued)

ID	Authors	Date	Title	Journal/Publisher	Volume/Pages	Geographic Scope	Scale	Abstract
485	Wang, Shu-Guang; Xian-Wei Liu; Hua-Yong Zhang; Wen-Xin Gong; Xue-Fei Sun; Bao-Yu Gao	2007	Aerobic granulation for 2,4-dichlorophenol biodegradation in a sequencing batch reactor	Chemosphere (journal) and Elsevier (publisher)	69:769-775	Other	lab	Development of aerobic granules for the biological degradation of 2,4-dichlorophenol (2,4-DCP) in a sequencing batch reactor was reported. After operation of 39 d, stable granules with a diameter range of 1–2 mm and a clearly defined shape and appearance were obtained. After granulation, the effluent 2,4-DCP and chemical oxygen demand concentrations were 4.8 mg/L and 41 mg/L with high removal efficiencies of 94% and 95%, respectively.
507	Drewes, Jorg E.; Christopher Bellona; Matthew Oedekoven; Pei Xu; Tae-Uk Kim; Gary Amy	2005	Rejection of Wastewater-Derived Micropollutants in High-Pressure Membrane Applications Leading to Indirect Potable Reuse	Environmental Progress (journal) and American Institute of Chemical Engineers (publisher)	24(4): 400-409	U.S.	full, lab	Rejection of emerging organic micropollutants was studied using a two-sage laboratory membrane skid and two full-scale RO trains. In general hydrophilic ionic compounds were efficiently removed by steric and electrostatic exclusion. Full-scale studies did not reveal any quantifiable detects of any target comound, except for low concentrations of caffein in the permate samples of the second and third stages of one facility. Findings suggest that fouling layers present on membranes in full-scale installations result in an improved rejection of hydropihilic nonionic and especially hydrophobic solutes.

Appendix D

DETAILED ABSTRACTS OF KEY REFERENCES

Key CECs Treatment References

1. Snyder, Shane; Eric C. Wert; Hongxia (Dawn) Lei; Paul Westerhoff; and Yeomin Yoon. *Removal of EDCs and Pharmaceuticals in Drinking and Reuse Treatment Processes.* 2007. American Water Works Association Research Foundation (AwwaRF) and IWA Publishing.

This study was funded and published by the American Water Works Association Research Foundation (AwwaRF Project #2758). Researchers selected 36 EDCs and pharmaceuticals for evaluation based upon their occurrence, chemical structure, and usefulness as surrogates for classes of similar contaminants. Researchers developed an analytical procedure in which solid phase extraction was used for a single 1-liter sample. The extract was split into two fractions, one analyzed using GC-MS/MS and the other using LC-MS/MS.

Researchers investigated unit processes currently used to treat drinking water and some novel processes. The target compounds were spiked at ng/L concentrations into various natural waters, and their removal by physical, chemical, and biological water treatment processes was evaluated in batch mode (bench-scale) and/or dynamically in a flow-through mode (pilot-scale). Full-scale drinking water and water reuse treatment facilities were assessed by analyzing samples of raw water, water representing unit processes, and finished water. Observations of removal from full-scale facilities were compared to those made at bench- and pilot-scale. Researchers found:

- Coagulation, flocculation, and filtration provided poor removal of the contaminants evaluated.
- Disinfection using free chlorine oxidized approximately half of the target compounds, including all phenolic steroid hormones.
- Disinfection using chloramine was far less efficient for contaminant oxidation than free chlorine.
- UV irradiation at disinfection dosages was ineffective for contaminant removal; however, UV advanced oxidation using hydrogen peroxide was highly effective for the removal of most studied contaminants.
- Ozone oxidation was capable of removing nearly all target analytes to below detection limits with or without the addition of hydrogen peroxide.
- Adsorption with activated carbon was highly effective using both powdered and granular forms; however, removal efficacy was a function of carbon type, contact time, water quality, and contaminant structure.
- Magnetic ion exchange resin (MIEX) was ineffective for the removal of most EDC/PPCP compounds.
- Nanofiltration and reverse osmosis both showed excellent contaminant rejection, while microfiltration and ultrafiltration offered only meager contaminant removal.

It is unrealistic to test the fate and removal of the hundreds of pharmaceutical and potential EDCs. For this reason, the researchers explored the efficacy of developing models to predict treatment process outcomes. For seven water treatment processes, they used quantitative structural-property relationship (QSPR) and quantitative structural-activity relationship (QSAR) computer models to predict treatment efficiency based on structural properties. The fate and properties of small number of chemicals was modeled. Additional model development would enable researchers to provide rapid evaluation of the likelihood that a particular chemical will be removed by a particular treatment process.

2. Stephenson, Roger; and Joan Oppenheimer. *Fate of Pharmaceuticals and Personal Care Products through Municipal Wastewater Treatment Processes.* 2007. Water Environment Research Foundation (WERF) and IWA Publishing.

This study, sponsored by WERF, was conducted to expand the limited published data describing the removal of Pharmaceuticals and Personal Care Products (PPCPs) from full-scale wastewater treatment facilities. Researchers measured the removal of 20 PPCPs commonly found in wastewater treatment plant influents. They studied six U.S. wastewater treatment systems that employed varying combinations of treatment operations, including: activated sludge, media filtration, chlorine disinfection, ultraviolet disinfection, and reverse osmosis. The also studied two pilot-scale membrane bioreactors (MBRs). Key study conclusions are:

- Increased sludge retention time (SRT) enhances removal of the majority of monitored PPCPs.
- SRT required to achieve consistent removal above 80% ($SRT_{80\%}$) is compound-specific. Many moniotored PPCPs are well removed with SRTs of 5 – 15 days.
- $SRT_{80\%}$ of more than 30 days was observed for the fragrances galaxolide and musk ketone, and tri(chloroethyl) phosphate (a fire retardant).
- Activated sludge removes many PPCPs, but a second barrier may be necessary for some target compounds.

3. Drewes, Jorg E.; Jocelyn D.C. Hemming; James J. Schauer; and William C. Sonsogni. *Removal of Endocrine Disrupting Compounds in Water Reclamation Processes*. 2006. Water Environment Research Foundation (WERF) and IWA Publishing.

This study, sponsored by WERF, was conducted to develop approaches combining bioassays with chemical analysis to study removal of endocrine disrupting compounds by water reclamation treatment processes. Eleven treatment plants were sampled in the U.S. for testosterone, four estrogenic hormones, and four phenolic compounds (bisphenol A and alkylphenol degradation products, 4-nonylphenol, 4-(tert-Octyl)phenol and 4-octylphenol). Wastewater samples were extracted with solid phase extraction and analyzed by GC-MS and HPLC-ELISA. Sample extracts were also analyzed using four *in vitro* bioassays, two for estrogenic activity and two for androgenic activity. Researchers found a strong relationship between the GC-MS results and the estrogenic activity bioassays. In contrast, researchers found a poor relationship between the GC-MS results and the androgenic activity bioassays, suggesting that testosterone was not the only androgenic hormone present in the wastewater samples. The estrogenic *in vitro* bioassays were robust tools for following changes in activity during wastewater treatment.

The wastewater treatment plants employed varying combinations of treatment operations, including: activated sludge, media filtration, chlorine disinfection, ultraviolet disinfection, reverse osmosis, MBRs, and soil-aquifer technology. Researchers found that conventional secondary treatment can provide substantial removals of EDCs compounds and activities. For the studied compounds, they found no significant improvement in removal between two and ten days of SRT. Advanced treatment processes, such as activated carbon, reverse osmosis membranes, and soil-aquifer treatment provided additional removal.

4. Lishman, Lori; Shirley Anne Smyth; Kurtis Sarafin; Sonya Kleywegt; John Toito; Thomas Peart; Bill Lee; Mark Servos; Michel Beland; and Peter Seto. *Occurrence and Reductions of Pharmaceuticals and Personal Care Products and Estrogens by Municipal Wastewater Treatment Plants in Ontario, Canada.* May 2006. Science of the Total Environment. 367: 544-558.

This study was sponsored by National Water Research Institute of Environment Canada. The goal of the study was to establish a Canadian database for the presence of 18 CECs, including acidic drugs, triclosan, polycyclic musks, and selected estrogens in municipal wastewater treatment plant influent and effluent. Samples were collected from 12 Ontario treatment plants that employed lagoons, activated sludge, and activated sludge with filtration treatment systems. All samples were filtered 1.2 μm glass fiber filter paper before extraction and GC/MS analysis. Hydrophobic compounds may sorb to the filters and be lost from the sample, so measured concentrations of these compounds may be erroneously low. EPA notes that the low concentration bias would apply to both influent and effluent samples, so the effect on calculated percent removal is ambiguous. EPA further notes that it has not screened all reviewed references for sample handling procedures. For these reasons, EPA has not excluded this study from the *CECs Removals Database*.

In addition to removals, investigators calculated per capita generation rates for commonly detected compounds. The study demonstrates that there are detectable levels of PPCPs entering Canadian waterways at trace levels, and that only some of these compounds are being reduced in a significant proportion by municipal wastewater treatment processes.

5. Clara, M.; N. Kreuzingera; B. Strenna; O. Gansb; H. Kroissa. The Solids Retention Time--A Suitable Design Parameter to Evaluate the Capacity of Wastewater Treatment Plants to Remove Micropollutants. 2005. Water Research. 39:97-106.

This study was part of EU-funded POSEIDON Project and partly funded by the Austrian government. Researchers studied the removal of four hormones, four pharmaceuticals, and bisphenol A in pilot- and full-scale treatment plants to identify substances for which a critical solid retention time (SRT) can be defined. Nine systems, including six full-scale activated sludge wastewater treatment systems with varying SRTs and three MBR pilot systems with varying SRTs, were studied.

Researchers found that some compounds (e.g., the antiepileptic drug carbamazepine) were not removed in any of the sampled treatment facilities. Removal of other compounds (diclofenac and 17α-ethinylestradiol) was variable and researchers concluded that SRT is not the only factor affecting removals. Researchers found a strong correlation between achievable effluent concentrations and SRT for bisphenol-A, ibuprofen, bezafibrate and the natural estrogens. For these compounds, they found a critical SRT of approximately 10 days, which corresponds to the SRT for nitrogen removal (nitrification, denitrification).

6. Clara, M.; B. Strenn; O. Gans; E. Martinez; N. Kreutzinger; and H. Kroiss. Removal of Selected Pharmaceuticals, Fragrances and Endocrine Disrupting Compounds in a Membrane Bioreactor and Conventional Wastewater Treatment Plants. 2005. Water Research 39: 4797-4807.

This study was part of EU-funded POSEIDON Project and partly funded by the Austrian government. The study compared the performance of a pilot-scale MBR to conventional activated sludge plants operated at different SRTs. Researchers measured the concentrations of eight pharmaceuticals, two polycyclic musk fragrances, and nine alkylphenols and alkylphenol ethoxylates (APEs) in treatment plant influent and effluent. They found no difference between in removal of target compounds by MBR and activated sludge. The ultrafiltration membranes used in the MBR did not improve removal of target compounds. Some compounds (e.g., the antiepileptic drug carbamazepine) were not removed in any of the sampled treatment facilities. Other compounds (e.g., bisphenol-A and ibuprofen) were nearly completely removed. Activated sludge plants operated at the longer SRTs used for nitrogen removal increased the removal of other compouds, (e.g, APEs). An unknown amount of the removal of APEs and musk compounds is likely attributable to adsorption to solids.