EPA

Treating Contaminants of Emerging Concern

A Literature Review Database

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1. INTRODUCTION

Contaminants of emerging concern (CECs), including pharmaceuticals and personal care products (PPCPs), have been detected at low levels in surface water, leading to concerns that these compounds may have an impact on human health and aquatic life.

This report contains the results of an extensive review of the recent literature on wastewater treatment technologies and their ability to remove a number of chemical contaminants of emerging concern (CECs). The data in the studies described in the literature are also available in a computer-searchable format. EPA developed this information to provide an accessible and comprehensive body of historical information about current CEC treatment technologies for wastewater. Wastewater treatment plant operators, designers, and others may find this information useful in their studies of ways to remove CECs from wastewater. In this report, EPA is not promoting any one technology nor is EPA setting Agency policy or priorities in terms of risk. The literature review report and the searchable file were peer-reviewed for completeness and usability.

Because the keywords we used to search the literature included the word "water" some papers described studies of drinking water treatment for CECs. The data from these studies are included in this report and the companion searchable file. However, this information is not as comprehensive or inclusive as a search for CEC treatment, if drinking water had been a keyword.

In addition, use of the term "removals" simply means less of the target chemical was observed after treatment than before treatment. Removal percentage is defined as:

$$100 \times (\text{influent concentration} - \text{effluent concentration})/\text{influent concentration}$$

For many chemicals and treatment technologies, removal of a target chemical can be a removal from the water, including transfer to solids or transfer to air. Biological and chemical oxidation can transform contaminants to simple molecules such as carbon dioxide and water. On the other hand, removals may simply reflect a transformation of the target chemical to another chemical or chemicals in the water. These new chemicals may or may not be of equal or greater concern than the parent contaminant.

To house the data gathered in the literature review, EPA developed a relational database to store information about the reports reviewed, the technologies studied, and their performance. The database is intended as a tool for individuals interested in identifying information about the performance of particular treatment technologies. This report describes the database and illustrates how it can be used, but it does not present conclusions about treatment system performance in removing CECs from water and wastewater. This report has been through both internal and external peer review; and the reviewer comments were incorporated as appropriate.

After presenting general background information about CECs, this introduction describes how EPA identified candidate technical literature for this review and highlights the organization of this report. This section also identifies and describes the information appended to the report.

1.1 Background

CECs include alkylphenols, flame retardants, hormones, personal care products, pharmaceuticals, steroids, and pesticides. Many CECs enter municipal wastewater through bathing, cleaning, laundry, and the disposal of human waste and unused pharmaceuticals. Municipal wastewater treatment plants typically use secondary treatment (i.e., activated sludge) to treat biological oxygen demand (BOD) and total suspended solids (TSS). Most municipal wastewater treatment plants also disinfect to inactivate and/or remove pathogens, and many use advanced treatment systems to treat other pollutants, most notably nutrients. Municipal wastewater treatment plants are not designed to specifically remove CECs from wastewater. There have been, however, a growing number of reports that CECs removals occur in municipal wastewater treatment plants with secondary treatment, as well as, those with some form of advanced treatment.

CECs are also detected in drinking water supplies, particularly those drawn from surface waters into which treated municipal wastewaters are discharged. Drinking water treatment plants typically use coagulation/flocculation and granular filtration to remove colloidal and suspended solids. After solids removal, treated drinking water is disinfected to inactivate and/or remove pathogens. Like municipal wastewater treatment plants, although drinking water treatment plants are not designed to remove CECs; however, removals do occur. The extent of removal varies with the specific CEC and type of drinking water treatment.

EPA's Office of Water has a Literature Inventory designed to identify research relevant to CECs in the environment. To develop this inventory, EPA queried literature databases available through U.S. National Library of Medicine (PubMed) and Thomson Scientific (Web of Science) using author citations and topical keywords. The Literature Inventory provided over 400 articles that referenced treatment of CECs, from which EPA selected a subset based on specific criteria. It is this subset that forms the basis of this report.

1.2 About this Report

This report describes The *CECs Removals Database*, a Microsoft Access® database designed to store and manage information from published scientific studies of the removal of CECs from water and wastewater. The report does not present an analysis of the database information. For illustrative purposes, the report presents 16 of the over 200 CECs present in the database, and the average percent removals achieved by full-scale treatment systems that employ six of the greater than 20 reported treatment technologies. EPA makes no conclusions about these results, but provides them only to illustrate how the database may be used.

This report presents:

- A description of the criteria EPA used to identify data for the database;
- A description of the organization of the information in the database;
- As an illustration of database output, a description of removal efficiencies for 16 CECs achieved by full-scale treatment systems that use six selected treatment technologies.

1.3 Report Appendices

To supplement the descriptions provided in the body of the report, the following four appendices are included.

Appendix A: CEC Removals Database Output Tables. The literature reviewed for this report included studies of CECs in ten different materials. Appendix A presents tables of percent removals for three of these materials: municipal wastewater, drinking water, and treated effluent (secondary or tertiary treated). User manipulation of the database will allow for analysis of all 10 reported materials. Studies of these three materials were selected for Appendix A because these materials were the most frequently studied in full-scale treatment systems. For each of these three materials, Appendix A includes percent removals from studied full-scale, pilot-scale, and laboratory-scale treatment systems. EPA used the database to calculate removal efficiencies for all studied CECs for the treatment technologies commonly studied for each material, as follows:

- Municipal Wastewater:
  - activated sludge,
  - fixed film biological treatment,
  - chemical phosphorus removal,
  - biological phosphorus removal,
  - denitrification,
  - nitrification,
  - chlorine disinfection,
  - granular activated carbon,
  - ozonation,
  - reverse osmosis, and
  - ultraviolet disinfection;

- Drinking Water:
  - chlorine disinfection,
  - granular activated carbon,
  - ozonation, and
  - ultraviolet disinfection;

- Treated effluent (secondary or tertiary treated):
  - activated sludge,
  - fixed film biological treatment,
  - chlorine disinfection,
  - granular activated carbon,
  - ozonation,
  - reverse osmosis,
  - ultrafiltration, and
  - ultraviolet disinfection.

Appendix B: Contaminants of Emerging Concern (CECs) Removals Database Version 3 User's Guide For the Non-Access®-Trained User. EPA has made the CECs Removal Database available to the public on its website. As part of this database, EPA developed an Access® form called

"Quick Search" that enables users to select the type of studies of interest and then produce a report of their percent removals. The *User's Guide* presents step-by-step instructions for using the Quick Search form.

Appendix C: CEC Removal Database Bibliography. Appendix C provides a complete list and short abstracts of the 88 articles from which information was extracted for the *CECs Removals Database*. The information provided includes:

- Authors;
- Date;
- Title;
- Journal/Publisher;
- Volume/Pages;
- Geographic Scope;
- Scale (Full-, Pilot-, or Laboratory-); and
- Abstract.

Appendix D: Detailed Abstracts of Key References. Appendix D provides more detailed abstracts for key studies that provided information for larger numbers of treatment systems or particular insights into CECs removal efficiencies. These references are:

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.

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.

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.

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.

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.

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.

2. TREATMENT TECHNOLOGY LITERATURE SELECTION CRITERIA

In order to compile information on CEC treatment technologies, EPA reviewed published studies that report the removal of CECs from water and wastewater by both commonly used and innovative treatment technologies. These studies, mostly from the CEC Literature Inventory, included laboratory-scale (a system that is operated from a laboratory bench and tests are run in batches), pilot-scale (a system that runs as a non-permanent subunit of a full-scale system), and full-scale (a fully-functioning, permanent treatment system) treatment systems.

Among the reviewed studies are research reports prepared for the Water Environment Research Foundation (WERF), the Water Research Foundation[1], the WateReuse Foundation, and EPA. Only references meeting the following quality criteria were reviewed:

- The reference was published between 2003 and 2008 (i.e., it was not more than five years old at the time of the review), to ensure that information reflected current conditions and analytical methods.

- The reference represents a primary source. EPA did not include data compiled in review articles. Further, EPA limited the sources included in its literature reviews to works by academic researchers from:
  - Peer-reviewed research reports; and/or
  - Peer-reviewed journal publications.

- The analytes studied were in the following general classes:
  - Pharmaceuticals and personal care products;
  - Steroids and hormones;
  - Pesticides;
  - Nonlyphenols, octylphenol, and alkylphenol ethoxylate (APEs) compounds;
  - Polybrominated biphenyl ether (PBDE) fire retardants;
  - Polynuclear aromatic hydrocarbons (PAHs); and
  - Other chemicals: e.g., bisphenol A, fire retardants and plasticizers.

- The article was available as a complete document and was available in English.

- EPA included studies from any geographic location; the various reports are identified by study location as U.S., Canada, Europe, or other (including Australia). Database users can develop queries to select the location(s) relevant to their analysis.

EPA next determined if the published article contained data for CECs and treatment processes within the scope of the study. Articles with the following types of information were excluded:

- Study focused on removal rates and did not determine efficiency of a complete process;

[1] The Water Research Foundation was formerly known as the American Water Works Research Foundation (AWWARF).

- Only influent concentrations were reported (with no effluent concentrations or percent removal reported);
- Only effluent concentrations were reported (with no influent concentrations or percent removal reported); or
- Only bioassay results were reported (no concentrations of individual compounds).

EPA began the review with over 400 articles discussing CEC treatment and identified a total of 88 studies that meet these criteria. These 88 studies had analytical data for 596 different treatment systems; 199 full-scale systems, 135 pilot-scale systems and, 262 lab-scale systems. Sixty-five of these studies had analytical data for individual unit processes within the systems. See Appendix C for a complete list and short abstracts of the 88 articles.

3. CEC REMOVALS DATABASE

To capture the data identified by the literature search in an accessible manner, EPA entered the CEC removal efficiencies into a Microsoft Access® database (hereafter, "the database"). The database captures bibliographic information about the data source as well as information about the analytes studied, the treatment unit processes employed, the types of water treated, and the performance of the studied treatment system. It includes treatment system influent and effluent concentrations or percent removal, as reported by the reference and data surrounding individual unit processes, when provided. The database does not contain information about the concentration of CECs in sludges or other residuals generated during treatment of water or wastewater. The types of treatment systems in the database are identified by the treatment codes listed in Table 1.

Data were entered into the database as presented in the published reports; however, data were only used to calculate removal efficiencies if:

1. Influent concentration was detected and was greater than the effluent concentration; and

2. The effluent detection limit was provided if the effluent concentration was reported as ND (not detected).

These criteria were used to facilitate calculation of average removal efficiencies from multiple sources. EPA recognizes limitations of this approach. CECs may enter the treatment plant as precursors or conjugates that then break down to form the CEC. Because the precursor or conjugate is not measured as the CEC, the influent concentration is less than the effluent concentration and the resulting calculated "removal efficiency" is negative (for example, if the influent concentration is 5 ng/L and the effluent concentration is 10 ng/L, the removal efficiency will be minus 100%).

EPA notes that data that do not meet the criteria listed above are included in the database and are available to users who choose different criteria (for example, influent concentrations may be less than effluent concentrations).

If a treatment system had multiple concentration values for a sampling point, the paired data points that met the criteria above were averaged to generate a single percent removal for each analyte in a treatment system.

Table 1. Treatment Codes

Treatment Type	Subcategories/Variations	Code	Number of Full-Scale Systems	Number of Pilot-Scale Systems	Number of Lab-Scale Systems
Aerobic granulation	none	AGR	0	0	1
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	98	2	60
Activated sludge + nutrient removal	activated sludge + nutrient removal (nitrification, denitrification, biological phosphorus removal, etc.)	ASN	8	0	0
Biological activated carbon	none	BAC	4	2	2
Phosphorus removal (biological)	biological	BP	4	0	10
Chlorine disinfection	chlorination, dechlorination, chloramination	CL	43	0	19
Phosphorus removal (chemical)	chemical	CP	33	0	0
Coagulation or softening	addition of chemicals to enhance precipitation of unwanted compounds	CS	34	20	25
Denitrification	separate stage/sludge denitrification	DEN	29	9	13
Electrodialysis	desalination	ED	0	1	1
Electrolysis	none	EL	0	0	40
Fixed film biological treatment	fixed bed reactor, rotating biological contactor, trickling filter	FF	7	0	16
Granular activated carbon	none	GAC	7	2	5
Hydrogen peroxide	usually coupled with UV disinfection or ozonation	HYPR	1	0	2
Ion exchange	magnetic ion exchange resin (MIEX)	ION	0	2	7
Lagoon	none	LAG	15	0	5
Membrane bio reactor	none	MBR	2	31	5
Microfiltration	pore diameter range is 0.09 to 10 micrometers	McF	15	4	1
Media filters	granular media filters, deep bed filters, cloth disc filters; pore diameter range is 10 to 100 micrometers	MF	52	14	4
Nanofiltration	pore diameter range is <0.001 to 0.01 micrometers	NF	0	3	16

Table 1. Treatment Codes (Continued)

Treatment Type	Subcategories/Variations	Code	Number of Full-Scale Systems	Number of Pilot-Scale Systems	Number of Lab-Scale Systems
Nitrification	separate stage/sludge nitrification	NT	29	9	0
Ozonation + hydrogen peroxide	advanced oxidation process with ozonation and H2O2 coupled	OZ/H2O2	0	20	4
Ozonation + ultraviolet disinfection	advanced oxidation process with ozonation and UV light	OZ/UV	0	1	0
Ozonation	none	OZN	15	32	22
Powdered activated carbon	none	PAC	1	4	8
Reed bed	constructed wetlands	RB	3	9	0
Reverse osmosis	none	RO	15	11	5
Soil-aquifer treatment	groundwater recharge, natural treatment	SAT	6	3	3
Septic systems	septic tank	SEP	1	0	0
Settling tank	clarification, settling, sedimentation	ST	92	9	5
Ultrafiltration	pore diameter range is 0.004 to 0.1 micrometers	UF	2	2	11
Ultraviolet + hydrogen peroxide	advanced oxidation process with UV light and H2O2 coupled	UV/H2O2	1	6	14
Ultraviolet disinfection	none	UVD	15	8	16
TOTAL			**199**	**135**	**262**

[a] Total number of systems included in *CECs Removal Database Version 3*. Systems may have more than one treatment type.

In addition to concentrations at the influent and effluent from the full system, researchers often measured concentrations at intermediate points. Influent and effluent data characterize a treatment system while data collected before and after one step of the treatment system only characterize the performance of that unit process. EPA captured these two types of information by reporting data separately for treatment systems and unit processes. For example, as depicted in Figure 1, a wastewater treatment plant was sampled at influent, effluent, and some intermediate steps. In the database, raw (untreated) influent and final effluent (after dechlorination) data are entered to characterize removal efficiencies from the full treatment system. To characterize the unit process of media filtration, data are entered from the sample collection points immediately before and after this process (Step 1 and Step 2, respectively, as depicted in Figure 1). No other unit processes are completely isolated in this system, so no other datasets are recorded. The database allows the user to select removal averages for entire treatment systems or for isolated unit processes.

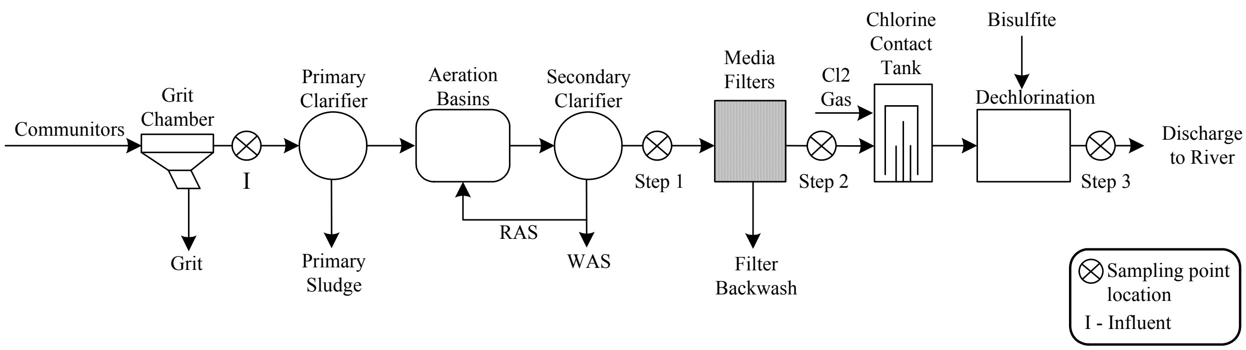


Figure 1. Three-Step Wastewater Treatment System

In some references, instead of reporting paired influent and effluent concentrations, the authors reported calculated percent removal. When concentration data were not available, published removal percentages were entered provided that the reported percent removal were greater than 0 and equal to or less than 100. In other references, authors presented results in graphical form and the underlying measured concentrations were not reported. In these cases, the authors were contacted for the underlying concentrations data.

Influent and/or effluent concentrations were sometimes preceded by a “<” or “>” flag. When flagged concentrations were used in a calculation, the resulting percent removal was also flagged. For example, if the influent was reported as 10 ng/l and the effluent was reported as <5 ng/l, the percent removal was reported as >50%. Similarly, if the influent was reported as >10 ng/l and the effluent was reported as 5 ng/l, the percent removal was reported as <50%. If the influent and effluent are both flagged, the percent removal cannot be identified as a minimum or maximum and was not flagged. In some cases, the study reported only flagged percent removal. In these cases, the reported flags are retained in the *CEC Removals Database*.

The database uses matrix codes to identify the material studied in the reference. The “matrix” is the type of water in which CECs occur; for example, ground water, surface water, and municipal wastewater. Table 2 shows the matrix codes and the number of systems treating each matrix that are included in the database.

Table 2. Matrix Codes

Matrix Type	Code	Number of Full-Scale Systems	Number of Pilot-Scale Systems	Number of Lab-Scale Systems
Clean Water (distilled)	CW	0	0	43
Drinking Water (unspecified source water to drinking WTP)	DW	38	2	3
Groundwater	GW	0	2	0
Human Waste	HW	0	0	5
Industrial Wastewater	IWW	0	2	2
Municipal Wastewater	MUW	120	37	34
Manure Waste	MW	2	0	1
Surface Water	SUW	6	60	98
Synthetic Wastewater	SWW	0	0	33
Treated Effluent (secondary or tertiary treated)	TE	33	32	43
TOTALS		**199**	**135**	**262**

The database allows users to retrieve stored information. EPA has made the *CECs Removal Database* available to the public on its website. As part of this database, EPA developed an Access® form called "Quick Search" that enables users to select the type of study of interest and then produces a report of their percent removals. The *User's Guide*, included as Appendix B, presents step-by-step instructions for using the Quick Search form.

4. FULL-SCALE TREATMENT TECHNOLOGY PERFORMANCE: AN ILLUSTRATION

To illustrate information that can be retrieved from the database, this section discusses the performance of full-scale treatment systems that incorporate one of six commonly used treatment technologies. EPA selected 16 CECs to highlight in this discussion.

The database contains information on 246 CECs, divided into seven classes, as presented in Table 3.

Table 3. CECs Classes

General Class	General Class Abbreviation
Nonlyphenols, octylphenol, and alkylphenol ethoxylate (APEs) compounds	NP/APEs
Polynuclear aromatic hydrocarbons	PAH
Polybrominated biphenyl ethers	PBDEs
Pesticide	Pesticide
Pharmaceuticals and personal care products	PPCP
Steroids and Hormones	S/H
Other	Other

For the purpose of the illustration presented in this section, EPA selected 16 of these 246 CECs using the following steps. EPA ranked the CECs in the database by number of full-scale systems for which removal efficiencies were calculated. EPA selected the top ranking 15 CECs. These CECs represent the following classes: PPCPs, pesticides, steroids and hormones, and other. EPA added a 16th CEC, nonylphenol, to the performance review in this section because it is the highest ranking CEC in the NP/APEs class. EPA did not include PBDEs and PAHs in this illustration because the database includes few calculated removal efficiencies for CECs in these classes.

The six treatment technologies discussed in this section are activated sludge, granular activated carbon adsorption, chlorine disinfection, ultraviolet disinfection, ozone disinfection, and reverse osmosis.

EPA collected data on laboratory-, pilot-, and full-scale treatment systems; however, this section presents information on removal efficiencies across full-scale treatment systems, only. Full-scale systems are highlighted because they reflect actual treatment scenarios. Lab- and pilot-scale systems do not take into account all of the variables that a full-scale drinking water or wastewater treatment plant may actually encounter on a day-to-day basis. Information on lab- and pilot-scale systems and on unit processes can be found in the database. However, many of the lab- and pilot-scale results were similar to the full-scale results presented below.

Two of the 16 CECs discussed in this section are naturally occurring estrogens (estradiol and estrone). The other 14 CECs include ten PPCPs, one pesticide, one surfactant (nonylphenol, NP), one flame retardant (tri(chloroethyl) phosphate) and one plasticizer (Bisphenol A).

The removal efficiencies calculated by the database are not based on a mass balance. They do not account for removal mechanisms such as potential sludge partitioning, or volatilization to air, and only consider the concentrations in the influent and effluent streams. Additionally, inclusion of analytes in this report does not reflect a determination that their presence in wastewater adversely affects human health or the environment. For each treatment technology discussed in this section, the following information is presented:

- A brief description of the process and its use in treating water and wastewater;

- A table presenting the removal of the 16 CECs in full-scale systems treating:
  - Municipal wastewater;
  - Treated effluent[2] (secondary or tertiary treated); or
  - Drinking water.

[2]Treated effluent in these studies is further treated in reuse/reclaimed water facilities. The influent to the system comes directly from the effluent of a wastewater treatment plant.

4.1 Activated Sludge

Activated sludge is a two-stage suspended growth biological treatment process designed to remove organic material measured as biochemical oxygen demand (BOD). The first stage is an aerated reactor in which organic material is removed by a mixed microbial population. The second stage is a settling tank (clarifier) that removes solids (activated sludge) from wastewater. A portion of the activated sludge is wasted and the remainder is returned to the aerated reactor. Because solids are returned to the reactor, their residence time in the system is greater than the hydraulic residence time. For conventional activated sludge, the average solids retention time is 5 to 10 days. CECs may be removed from wastewater during activated sludge treatment by biodegradation and/or by adsorption to the solid material wasted from the system.

The activated sludge process is the most common type of secondary treatment used in U.S. municipal wastewater treatment plants. The activated sludge studies presented here do not include activated sludge systems that reported design modifications including those that remove nutrients[3]. There are many variations on this process; CECs removal data from several types of activated sludge processes are included in the database, further division of activated sludge categories was impractical based on the descriptors provided in the studies.

For treatment of the 16 CECs in full-scale activated sludge treatment systems, the average reported removal efficiencies are listed in Table 4. Effectiveness of activated sludge treatment varied by type of water treated. For municipal wastewater, the average removal efficiencies for activated sludge treatment ranged from 22% for carbamazepine to 94% for caffeine.

[3] The database includes two forms of biological nutrient removal (BNR), specifically de-nitrification and biological phosphorus removal; however, when looking at the compiled data, systems with BNR seem to remove CECs less effectively than a treatment system with a more conventional activated sludge system.

Table 4. Removal of 16 Selected Analytes by Full-Scale Activated Sludge Treatment

Analyte	Group	Drinking Water				Treated Effluent				Municipal Wastewater			
		Avg % Removal	Min Removal	Max Removal	# Systems Used to Calculate Removal	Avg % Removal	Min Removal	Max Removal	# Systems Used to Calculate Removal	Avg % Removal	Min Removal	Max Removal	# Systems Used to Calculate Removal
Bisphenol A	Other	NR	NR	NR	0	NR	NR	NR	0	78	11	100	41
Caffeine	PPCP	NR	NR	NR	0	30	2.6	48	3	94	85	100	7
Carbamazepine	PPCP	NR	NR	NR	0	22	3.5	40	2	22	< 10	60	5
DEET	pesticide	NR	NR	NR	0	46	17	> 74	2	54	16	> 84	7
Diclofenac	PPCP	NR	NR	NR	0	47	18	> 82	3	44	7.1	> 99	23
Estradiol	S/H	NR	NR	NR	0	NR	NR	NR	0	88	44	100	49
Estrone	S/H	NR	NR	NR	0	74	> 58	90	2	77	1.8	100	46
Galaxolide	PPCP	NR	NR	NR	0	NR	NR	NR	0	56	9	99	25
Gemfibrozil	PPCP	NR	NR	NR	0	75	59	92	2	77	38	> 99	13
Ibuprofen	PPCP	NR	NR	NR	0	28	5.6	50	2	90	43	100	32
Iopromide	PPCP	NR	NR	NR	0	55	55	55	1	69	50	83	3
Naproxen	PPCP	NR	NR	NR	0	98	> 98	> 98	1	85	47	100	18
Nonylphenol	NP/APEs	NR	NR	NR	0	NR	NR	NR	0	90	57	100	26
Sulfamethoxazole	PPCP	NR	NR	NR	0	49	25	93	3	58	9	99	15
Tri(chloroethyl) phosphate	Other	NR	NR	NR	0	6.5	6.5	6.5	1	27	4.5	50	2
Triclosan	PPCP	NR	NR	NR	0	79	> 79	> 79	1	89	> 67	100	22

NR – Not reported.

4.2 Granular Activated Carbon Adsorption

Granular activated carbon adsorption is used to remove dissolved materials from solution. The dissolved materials are held on the activated carbon surface by chemical and physical bonding. In wastewater treatment, activated carbon is used in granular or powdered form. Granular activated carbon (GAC) is held in a fixed-bed column and the water or wastewater passes through the carbon bed. Granular activated carbon adsorption is a polishing treatment step, most commonly used to remove low concentrations of organic pollutants. Pollutants removed from water and wastewater will be adsorbed to the solid wastes generated by this process. Activated carbon adsorption is used in both drinking water and wastewater treatment.

For treatment of the 16 CECs in full-scale granular activated carbon treatment systems, the average reported removal efficiencies are listed in Table 5. Effectiveness of granular activated carbon treatment varied by type of water treated. For treated effluent, the database includes removal efficiencies for 10 of the 16 CECs. The average removal efficiencies for treated effluent ranged from 3.6% for naproxen to 63% for DEET.

Table 5. Removal of 16 Selected Analytes in Full-Scale Treatment Systems that Include Granular Activated Carbon Treatment

Analyte	Group	Drinking Water				Treated Effluent				Municipal Wastewater			
		Avg % Removal	Min Removal	Max Removal	# Systems Used to Calculate Removal	Avg % Removal	Min Removal	Max Removal	# Systems Used to Calculate Removal	Avg % Removal	Min Removal	Max Removal	# Systems Used to Calculate Removal
Bisphenol A	Other	NR	NR	NR	0	NR	NR	NR	0	100	100	100	1
Caffeine	PPCP	NR	NR	NR	0	11	5.6	16	2	NR	NR	NR	0
Carbamazepine	PPCP	72	> 60	85	2	8.3	1	16	2	NR	NR	NR	0
DEET	pesticide	75	> 75	> 75	1	63	63	63	1	NR	NR	NR	0
Diclofenac	PPCP	NR	NR	NR	0	59	50	> 69	2	NR	NR	NR	0
Estradiol	S/H	NR	NR	NR	0	NR	NR	NR	0	100	100	100	1
Estrone	S/H	NR	NR	NR	0	NR	NR	NR	0	100	100	100	1
Galaxolide	PPCP	NR	NR	NR	0	NR	NR	NR	0	NR	NR	NR	0
Gemfibrozil	PPCP	79	> 79	> 79	1	6.1	4	8.2	2	NR	NR	NR	0
Ibuprofen	PPCP	58	> 58	> 58	1	16	16	16	1	NR	NR	NR	0
Iopromide	PPCP	45	45	45	1	45	18	72	2	NR	NR	NR	0
Naproxen	PPCP	47	> 47	> 47	1	3.6	0.85	6.3	2	NR	NR	NR	0
Nonylphenol	NP/APEs	NR	NR	NR	0	NR	NR	NR	0	NR	NR	NR	0
Sulfamethoxazole	PPCP	42	> 17	67	2	49	15	84	2	NR	NR	NR	0
Tri(chloroethyl) phosphate	Other	NR	NR	NR	0	NR	NR	NR	0	NR	NR	NR	0
Triclosan	PPCP	NR	NR	NR	0	47	47	47	1	NR	NR	NR	0

NR – Not reported.

4.3 Chlorine Disinfection

Chlorine disinfection is used to inactivate pathogens in water or wastewater. Chlorine, typically as a gas or as concentrated hypochlorite liquid, is used to disinfect drinking water prior to its distribution to customers. Chlorine is also sometimes used to disinfect wastewater, particularly prior to reuse. Chlorinated wastewater may be dechlorinated prior to discharge to surface water, to prevent harm to aquatic life. In addition to inactivating microbes, chlorine can transform organic chemicals via oxidation and chlorination; however, the reaction of chlorine with organic material can generate chloroform and other potentially harmful disinfection byproducts.

For treatment of the 16 CECs in full-scale treatment systems that included chlorine disinfection, the average reported removal efficiencies are listed in Table 6. Effectiveness of chlorine disinfection varied by type of water treated. For municipal wastewater, the database includes removal efficiencies for 13 of the 16 CECs. The average removal efficiencies for municipal wastewater ranged from 4.5% for the flame retardant tri(chloroethyl) phosphate to 98% for caffeine.

Table 6. Removal[a] of 16 Selected Analytes in Full-Scale Treatment Systems that Include Chlorine Disinfection

Analyte	Group	Drinking Water				Treated Effluent				Municipal Wastewater			
		Avg % Removal	Min Removal	Max Removal	# Systems Used to Calculate Removal	Avg % Removal	Min Removal	Max Removal	# Systems Used to Calculate Removal	Avg % Removal	Min Removal	Max Removal	# Systems Used to Calculate Removal
Bisphenol A	Other	NR	NR	NR	0	NR	NR	NR	0	72	20	96	8
Caffeine	PPCP	29	7.4	67	9	44	40	48	2	98	> 96	100	2
Carbamazepine	PPCP	49	2.6	85	10	65	40	> 90	2	NR	NR	NR	0
DEET	pesticide	21	2.4	> 75	9	46	17	> 74	2	23	23	23	1
Diclofenac	PPCP	NR	NR	NR	0	61	41	> 82	2	66	18	90	3
Estradiol	S/H	NR	NR	NR	0	NR	NR	NR	0	78	47	> 96	8
Estrone	S/H	NR	NR	NR	0	90	90	90	1	37	0.87	> 84	9
Galaxolide	PPCP	11	> 11	> 11	1	NR	NR	NR	0	57	11	99	4
Gemfibrozil	PPCP	44	1.9	> 83	9	80	59	92	3	83	68	> 90	3
Ibuprofen	PPCP	31	5	> 58	6	49	5.6	> 90	3	78	43	100	5
Iopromide	PPCP	30	8.3	65	7	55	55	55	1	NR	NR	NR	0
Naproxen	PPCP	60	> 9.1	100	10	99	> 98	100	2	93	88	100	3
Nonylphenol	NP/APEs	NR	NR	NR	0	NR	NR	NR	0	NR	NR	NR	0
Sulfamethoxazole	PPCP	69	13	> 98	12	61	> 29	93	2	73	47	98	2
Tri(chloroethyl) phosphate	Other	45	8.6	> 85	6	6.5	6.5	6.5	1	4.5	4.5	4.5	1
Triclosan	PPCP	42	> 9.1	> 63	4	79	> 79	> 79	1	83	> 67	99	4

NR – Not reported.
[a] Calculated removals include transformation. The contaminant may be transformed to another chemical form that may or may not be of less concern than the parent contaminant.

4.4 Ultraviolet Disinfection

Ultraviolet disinfection is used to inactivate pathogens in water or wastewater. The energy of ultraviolet (UV) light cleaves bonds in organic molecules. It also reacts with water to create highly reactive hydroxyl radicals which react with organic molecules. Both processes can inactivate microbes and can also transform CECs in water and wastewater. The effectiveness of UV oxidation depends on the energy and wavelength of the light, the clarity of the water, and the target CECs. The effectiveness of UV oxidation can be enhanced by the addition of hydrogen peroxide to increase concentration of hydroxyl radicals.

For treatment of 16 selected CECs in full-scale treatment systems that included UV disinfection (without peroxide), the average reported removal efficiencies are listed in Table 7. Effectiveness of UV disinfection varied by type of water treated. For municipal wastewater, the database includes removal efficiencies for 13 of the 16 CECs. The average removal efficiencies for municipal wastewater ranged from 33% for sulfamethoxazole to 97% for caffeine and naproxen.

Table 7. Removal[a] of 16 Selected Analytes in Full-Scale Treatment Systems that Include UV Disinfection

Analyte	Group	Drinking Water				Treated Effluent				Municipal Wastewater			
		Avg % Removal	Min Removal	Max Removal	# Systems Used to Calculate Removal	Avg % Removal	Min Removal	Max Removal	# Systems Used to Calculate Removal	Avg % Removal	Min Removal	Max Removal	# Systems Used to Calculate Removal
Bisphenol A	Other	NR	NR	NR	0	NR	NR	NR	0	85	> 72	> 92	4
Caffeine	PPCP	42	42	42	1	4.1	2.6	5.6	2	97	> 89	100	5
Carbamazepine	PPCP	17	> 17	> 17	1	2.3	1	3.5	2	NR	NR	NR	0
DEET	pesticide	21	19	22	2	50	50	50	1	64	41	> 84	3
Diclofenac	PPCP	NR	NR	NR	0	34	18	50	2	89	86	91	3
Estradiol	S/H	NR	NR	NR	0	NR	NR	NR	0	76	61	> 98	3
Estrone	S/H	NR	NR	NR	0	58	> 58	> 58	1	74	22	96	4
Galaxolide	PPCP	14	8.3	> 23	3	NR	NR	NR	0	55	13	> 86	4
Gemfibrozil	PPCP	69	69	69	1	26	4	> 47	2	90	> 90	> 90	2
Ibuprofen	PPCP	NR	NR	NR	0	NR	NR	NR	0	90	> 81	100	6
Iopromide	PPCP	NR	NR	NR	0	18	18	18	1	NR	NR	NR	0
Naproxen	PPCP	NR	NR	NR	0	0.85	0.85	0.85	1	97	> 90	100	3
Nonylphenol	NP/APEs	NR	NR	NR	0	NR	NR	NR	0	NR	NR	NR	0
Sulfamethoxazole	PPCP	83	> 83	> 83	1	28	15	> 44	3	33	33	33	1
Tri(chloroethyl) phosphate	Other	5.3	5.3	5.3	1	NR	NR	NR	0	50	50	50	1
Triclosan	PPCP	NR	NR	NR	0	47	47	47	1	90	71	99	5

NR – Not reported.

[a] Calculated removals include transformation. The contaminant may be transformed to another chemical form that may or may not be of less concern than the parent contaminant.

4.5 Ozone Disinfection

Ozone disinfection is used to inactivate pathogens in water or wastewater. Ozone (O3) is a strong oxidant and disinfectant used both in drinking water and wastewater treatment. Ozone can directly oxidize CECs. It also reacts with water to create highly reactive hydroxyl radicals which react with CECs. The effectiveness of ozone oxidation can be enhanced by the addition of either hydrogen peroxide or UV light.

For treatment of the 16 selected CECs in full-scale treatment systems that included ozone disinfection (without hydrogen peroxide or UV light), the average reported removal efficiencies are listed in Table 8. Effectiveness of ozone disinfection varied by type of water treated. For treated effluent, the database includes removal efficiencies for 15 of the 16 CECs. The average removal efficiencies for treated effluent ranged from 38% for iopromide to 100% for diclofenac.

Table 8. Removal[a] of 16 Selected Analytes in Full-Scale Treatment Systems that Include Ozone Disinfection

Analyte	Group	Drinking Water				Treated Effluent				Municipal Wastewater			
		Avg % Removal	Min Removal	Max Removal	# Systems Used to Calculate Removal	Avg % Removal	Min Removal	Max Removal	# Systems Used to Calculate Removal	Avg % Removal	Min Removal	Max Removal	# Systems Used to Calculate Removal
Bisphenol A	Other	NR	NR	NR	0	86	76	100	3	96	90	100	3
Caffeine	PPCP	NR	NR	NR	0	95	95	95	1	NR	NR	NR	0
Carbamazepine	PPCP	NR	NR	NR	0	88	> 71	100	6	60	60	60	1
DEET	pesticide	NR	NR	NR	0	67	48	100	5	74	69	79	2
Diclofenac	PPCP	NR	NR	NR	0	100	> 100	> 100	1	NR	NR	NR	0
Estradiol	S/H	NR	NR	NR	0	95	> 93	97	2	100	100	100	2
Estrone	S/H	NR	NR	NR	0	76	> 29	100	3	94	84	100	3
Galaxolide	PPCP	NR	NR	NR	0	55	55	55	1	NR	NR	NR	0
Gemfibrozil	PPCP	NR	NR	NR	0	76	> 50	> 99	3	90	> 90	> 90	1
Ibuprofen	PPCP	NR	NR	NR	0	73	> 41	100	4	95	> 90	100	2
Iopromide	PPCP	NR	NR	NR	0	38	25	50	2	NR	NR	NR	0
Naproxen	PPCP	99	99	99	1	97	> 92	> 100	4	84	> 68	100	2
Nonylphenol	NP/APEs	NR	NR	NR	0	71	42	100	2	85	82	89	2
Sulfamethoxazole	PPCP	NR	NR	NR	0	93	> 90	99	4	96	96	96	1
Tri(chloroethyl) phosphate	Other	NR	NR	NR	0	NR	NR	NR	0	NR	NR	NR	0
Triclosan	PPCP	NR	NR	NR	0	89	> 69	100	4	99	99	100	2

NR – Not reported.
[a] Calculated removals include transformation. The contaminant may be transformed to another chemical form that may or may not be of less concern than the parent contaminant.

4.6 Reverse Osmosis (RO)

Reverse osmosis is a pressure- or vacuum-driven process that separates contaminants from water. Clean water is driven through the membrane, leaving a concentrated waste stream behind. The concentrate wastestream then requires further processing or disposal. Membrane filtration treatment processes are distinguished by the size of contaminants they remove. Microfiltration and ultrafiltration remove suspended or colloidal particles via a sieving mechanism based on the size of the membrane pores relative to that of the particulate matter. Nanofiltration and reverse osmosis membranes, which do not have definable pores, remove dissolved contaminants. For the purpose of the CECs Removals Database, "Membrane Filtration (MbrF)" includes ultrafiltration and nanofiltration. Microfiltration is included with media filters because they remove similar size particles. Reverse osmosis, which is used for desalination, is considered separately and is presented in Table 9.

For treatment of selected CECs in full-scale treatment systems that included RO, the average reported removal efficiencies are listed in Table 9. RO effectiveness varied by type of water treated. For treated effluent, the database includes removal efficiencies for 14 of the 16 CECs. The average removal efficiencies for treated effluent ranged from 81% for sulfamethoxazole to 100% for iopromide, triclosan, and naproxen.

Table 9. Removal of 12 Selected Analytes in Full-Scale Treatment Systems that Include Reverse Osmosis

Analyte	Group	Drinking Water				Treated Effluent				Municipal Wastewater			
		Avg % Removal	Min Removal	Max Removal	# Systems Used to Calculate Removal	Avg % Removal	Min Removal	Max Removal	# Systems Used to Calculate Removal	Avg % Removal	Min Removal	Max Removal	# Systems Used to Calculate Removal
Bisphenol A	Other	NR	NR	NR	0	NR	NR	NR	0	NR	NR	NR	0
Caffeine	PPCP	NR	NR	NR	0	99	96	100	5	96	> 96	> 96	1
Carbamazepine	PPCP	NR	NR	NR	0	98	> 90	100	6	NR	NR	NR	0
DEET	pesticide	NR	NR	NR	0	83	50	> 100	3	NR	NR	NR	0
Diclofenac	PPCP	NR	NR	NR	0	98	> 98	> 98	2	90	> 90	> 90	1
Estradiol	S/H	NR	NR	NR	0	93	> 88	> 98	5	NR	NR	NR	0
Estrone	S/H	NR	NR	NR	0	99	> 99	> 99	2	84	>84	>84	1
Galaxolide	PPCP	NR	NR	NR	0	99	> 99	> 99	1	32	32	32	1
Gemfibrozil	PPCP	NR	NR	NR	0	90	> 47	100	6	90	> 90	> 90	1
Ibuprofen	PPCP	NR	NR	NR	0	97	> 90	100	5	72	>72	>72	1
Iopromide	PPCP	NR	NR	NR	0	100	> 99	> 100	2	NR	NR	NR	0
Naproxen	PPCP	NR	NR	NR	0	100	100	> 100	3	90	> 90	> 90	1
Nonylphenol	NP/APEs	NR	NR	NR	0	NR	NR	NR	0	NR	NR	NR	0
Sulfamethoxazole	PPCP	NR	NR	NR	0	81	> 44	> 100	3	NR	NR	NR	0
Tri(chloroethyl) phosphate	Other	NR	NR	NR	0	97	> 97	> 98	2	NR	NR	NR	0
Triclosan	PPCP	NR	NR	NR	0	100	> 99	> 100	2	67	> 67	> 67	1

NR – Not reported.

5. DATABASE UTILITY

EPA reviewed technical reports of the performance of water and wastewater treatment technologies and organized the information collected during this review in a relational database. This database stores information about the reports reviewed, the technologies studied, and their performance. The database is intended as a tool for individuals interested in identifying information about the performance of particular treatment technologies.

Water and wastewater treatment plant operators can use the database to evaluate the likely current removal efficiency of their plant for an array of CECs. They can also evaluate potential future performance of various upgrades.

Appendix A

CECS REMOVALS DATABASE OUTPUT TABLES

The literature reviewed for this report included studies of CECs in ten different materials. Appendix A presents tables of percent removals for three of these materials: municipal wastewater, drinking water, and treated effluent (secondary or tertiary treated). Studies of these three materials were selected for Appendix A because these materials were the most frequently studied in full-scale treatment systems. For each of these three materials, Appendix A includes percent removals from studied full-scale, pilot-scale, and laboratory-scale treatment systems. EPA used the database to calculate removal efficiencies for all studied CECs for the treatment technologies commonly studied for each material, as follows:

- Municipal Wastewater:
  - activated sludge,
  - fixed film biological treatment,
  - chemical phosphorus removal,
  - biological phosphorus removal,
  - denitrification,
  - nitrification,
  - chlorine disinfection,
  - granular activated carbon,
  - ozonation,
  - reverse osmosis, and
  - ultraviolet disinfection;

- Drinking Water:
  - chlorine disinfection,
  - granular activated carbon,
  - ozonation, and
  - ultraviolet disinfection;

- Treated effluent (secondary or tertiary treated):
  - activated sludge,
  - fixed film biological treatment,
  - chlorine disinfection,
  - granular activated carbon,
  - ozonation,
  - reverse osmosis,
  - ultrafiltration, and
  - ultraviolet disinfection.

The following tables are included in this appendix:

- Table A-1: Municipal Wastewater Removal Efficiencies for Full Scale Treatment Systems

- Table A-2: Municipal Wastewater Removal Efficiencies for Pilot Scale Treatment Systems

- Table A-3: Municipal Wastewater Removal Efficiencies for Lab Scale Treatment Systems

- Table A-4: Drinking Water Removal Efficiencies for Full Scale Treatment Systems
- Table A-5: Drinking Water Removal Efficiencies for Pilot Scale Treatment Systems
- Table A-6: Drinking Water Removal Efficiencies for Lab Scale Treatment Systems
- Table A-7: Treated Wastewater Removal Efficiencies for Full Scale Treatment Systems
- Table A-8: Treated Wastewater Removal Efficiencies for Pilot Scale Treatment Systems
- Table A-9: Treated Wastewater Removal Efficiencies for Lab Scale Treatment Systems

Table A-1. Municipal Wastewater Removal Efficiencies for Full Scale Treatment Systems

GENERAL CLASS KEY: NP/APEs - nonylphenols, octylphenol, and alkylphenol ethoxylate compounds; PAH - polynuclear aromatic hydrocarbons; PBDEs - polybrominated diphenyl ether fire retardants; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

		Activated Sludge				Fixed Film Biological Treatment				Phosphorus Removal (biological)			
General Class	CEC	Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count
NP/APEs	4-(tert-octyl)phenol	>30	>98	87	17					>96	>96	96	1
NP/APEs	4-Nonylphenol	17	97	78	10					97	97	97	1
NP/APEs	Nonylphenol	>57	>100	90	26	>100	>100	100	1				
NP/APEs	Nonylphenol diethoxylate	79	99	90	6								
NP/APEs	Nonylphenol monoethoxylate	36	100	78	7								
NP/APEs	Nonylphenoxyethoxyacetic acid	46	46	46	1								
NP/APEs	Octylphenol	>58	>99	91	19	>99	>99	99	1				
NP/APEs	Octylphenol diethoxylate	72	82	77	2								
NP/APEs	Octylphenol monoethoxylate	29	98	73	4								
Other	2,7-Dichlorodibenzo-p-dioxin	71	71	71	1								
Other	4-cumylphenol	81	81	81	1								
Other	Bisphenol A	>11	>100	78	41	>85	>85	85	1	>86	>86	86	1
Other	Butylbenzyl phthalate	>20	>99	80	14								
Other	Di(2-ethylhexyl)phthalate	18	93	53	8								
Other	Dibutyl phthalate	71	100	88	8								
Other	Diethyl phthalate	91	100	98	7								
Other	Dimethyl phthalate	94	94	94	1								
Other	Tri(chloroethyl) phosphate	4.5	50	27	2								
Other	Triphenylphosphate	57	57	57	1								
PAH	Naphthalene												
PBDEs	PBDE-99												
pesticide	Chlorfenvinphos	67	67	67	1								
pesticide	DEET	>16	>84	54	7								
pesticide	Permethrins-peak 1	67	67	67	1								
PPCP	1,7-Dimethylxanthine	77	77	77	1								
PPCP	2-Phenylphenol	89	89	89	1					89	89	89	1
PPCP	3-Phenylpropionate	>70	>98	90	6								
PPCP	4-Acetylsulfamethoxazole	85	91	89	3								
PPCP	4-Chloro-m-cresol	>99	>99	99	1					>99	>99	99	1
PPCP	Acebutolol	85	85	85	1								
PPCP	Acetaminophen	>90	>100	97	4					>99	>99	99	1
PPCP	Acetylsalicylic acid	>90	>90	90	1								

Table A-1. Municipal Wastewater Removal Efficiencies for Full Scale Treatment Systems (Continued)

GENERAL CLASS KEY: NP/APEs - nonylphenols, octylphenol, and alkylphenol ethoxylate compounds; PAH - polynuclear aromatic hydrocarbons; PBDEs - polybrominated diphenyl ether fire retardants; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

		Activated Sludge				Fixed Film Biological Treatment				Phosphorus Removal (biological)			
General Class	**CEC**	**Min**	**Max**	**Avg**	**Count**	**Min**	**Max**	**Avg**	**Count**	**Min**	**Max**	**Avg**	**Count**
PPCP	Amoxicillin	93	93	93	1								
PPCP	Atenolol	<10	<84	61	4					84	84	84	1
PPCP	Azithromycin	30	93	54	3								
PPCP	Benzophenone	>71	>90	84	6								
PPCP	Benzyl salicylate	>72	>98	91	5								
PPCP	Bezafibrate	35	100	74	12					97	97	97	1
PPCP	BHA	>92	>92	92	1								
PPCP	Biosol	>99	>99	99	1					>99	>99	99	1
PPCP	Caffeine	>85	>100	94	7					100	100	100	1
PPCP	Carbamazepine	<10	<60	22	5								
PPCP	Carbamazepine 10,11-epoxide	54	54	54	1								
PPCP	Cashmeran	54	84	69	2								
PPCP	Cefaclor	96	96	96	1								
PPCP	Celestolide	>41	>99	73	9								
PPCP	Celiprolol	36	36	36	1					36	36	36	1
PPCP	Cephalexin	100	100	100	1								
PPCP	Chloramphenicol	94	96	95	2								
PPCP	Chlorophene	73	73	73	1					73	73	73	1
PPCP	Ciprofloxacin	59	89	73	5	76	76	76	1				
PPCP	Clarithromycin	9.0	91	35	5					54	54	54	1
PPCP	Clofibric acid	28	52	43	3					52	52	52	1
PPCP	Codeine	29	29	29	1								
PPCP	Crotamiton	98	98	98	2								
PPCP	Diclofenac	>7.1	>99	44	23					18	35	27	2
PPCP	Dipyrone	65	65	65	1								
PPCP	Erythromycin-H2o	6.0	92	31	5					25	25	25	1
PPCP	Ethyl-3-phenylpropionate	>14	>94	64	5								
PPCP	Gabapentin	>99	>99	99	1					>99	>99	99	1
PPCP	Galaxolide	>9.0	>99	56	25					44	44	44	1
PPCP	Galaxolide-lactone	49	58	54	2								
PPCP	Gemfibrozil	>38	>99	77	13					68	68	68	1
PPCP	Glibenclamide	45	45	45	1								
PPCP	Hydrochlorothiazide	76	76	76	1								

Table A-1. Municipal Wastewater Removal Efficiencies for Full Scale Treatment Systems (Continued)

GENERAL CLASS KEY: NP/APEs - nonylphenols, octylphenol, and alkylphenol ethoxylate compounds; PAH - polynuclear aromatic hydrocarbons; PBDEs - polybrominated diphenyl ether fire retardants; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

General Class	CEC	Activated Sludge				Fixed Film Biological Treatment				Phosphorus Removal (biological)			
		Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count
PPCP	Ibuprofen	>43	>100	90	32					87	96	92	2
PPCP	Indomethacin	>23	>99	78	8								
PPCP	Iohexol	89	89	89	1					89	89	89	1
PPCP	Iomeprol	89	89	89	1					89	89	89	1
PPCP	iopamidol	17	17	17	1					17	17	17	1
PPCP	Iopromide	50	83	69	3					83	83	83	1
PPCP	Ketoprofen	>9.0	>99	71	11					77	77	77	1
PPCP	Lincomycin	17	17	17	1								
PPCP	Mefenamic Acid	29	72	52	3								
PPCP	Methyl-3-phenylpropionate	>95	>100	97	3								
PPCP	Methylparaben	>78	>93	89	5								
PPCP	Metoprolol	<10	<65	32	4					65	65	65	1
PPCP	Musk ketone	8.0	85	36	4								
PPCP	Musk xylene	53	53	53	1								
PPCP	Naproxen	>47	>100	85	18					88	88	88	1
PPCP	Norfloxacin	85	85	85	1								
PPCP	Octylmethoxycinnamate	>39	>99	86	6								
PPCP	Ofloxacin	24	98	69	3								
PPCP	Oxybenzone	>8.0	>96	76	6								
PPCP	Paroxetine	91	91	91	1								
PPCP	p-Chloro-m-xylenol	>15	>98	77	7					80	80	80	1
PPCP	Penicillin V	40	40	40	1								
PPCP	Phantolide	>44	>99	71	2								
PPCP	Phenobarbital	>99	>99	99	1					>99	>99	99	1
PPCP	Phenytoin	44	44	44	1					44	44	44	1
PPCP	Pravastatin	62	62	62	1								
PPCP	Propranolol	28	65	47	2					65	65	65	1
PPCP	Propyphenazone	43	43	43	1								
PPCP	Ranitidine	42	42	42	1								
PPCP	Roxithromycin	20	93	44	9					33	33	33	1
PPCP	Sotalol	26	75	50	3					48	48	48	1
PPCP	Sulfadiazine	97	97	97	2								
PPCP	Sulfamethoxazole	9.0	99	58	15	33	33	33	1	24	24	24	1

Table A-1. Municipal Wastewater Removal Efficiencies for Full Scale Treatment Systems (Continued)

GENERAL CLASS KEY: NP/APEs - nonylphenols, octylphenol, and alkylphenol ethoxylate compounds; PAH - polynuclear aromatic hydrocarbons; PBDEs - polybrominated diphenyl ether fire retardants; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

General Class	CEC	Activated Sludge				Fixed Film Biological Treatment				Phosphorus Removal (biological)			
		Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count
PPCP	Sulfapyridine	47	95	67	3								
PPCP	Sulfathiazole	50	50	50	1								
PPCP	Tetracycline	33	85	66	3	64	64	64	1				
PPCP	Thymol	>78	>91	85	2								
PPCP	Tonalide	13	97	67	20					70	70	70	1
PPCP	Traseolide	9.0	81	55	9								
PPCP	Triclocarban	97	97	97	1								
PPCP	Triclosan	>67	>100	89	22	82	93	87	2	69	69	69	1
PPCP	Trimethoprim	8.5	100	60	10	77	77	77	1	69	69	69	1
PPCP	Valproic acid	>99	>99	99	1					>99	>99	99	1
S/H	17α-estradiol	52	63	58	2								
S/H	Androsterone	98	100	99	5								
S/H	Cholesterol	85	85	85	1								
S/H	Coprostanol	97	97	97	1								
S/H	Estradiol	>44	>100	88	49	>90	>90	90	2	94	94	94	1
S/H	Estriol	>18	>100	91	24					>90	>90	90	1
S/H	Estrogenic Activity	70	91	82	4								
S/H	Estrone	>1.8	>100	77	46	>61	>100	76	3	96	98	97	2
S/H	Ethinyl Estradiol	>0.77	>99	66	13	46	46	46	1	85	88	86	2
S/H	Etiocholanolone	82	99	92	5								
S/H	Stigmasterol	98	98	98	1								
S/H	Testosterone	>51	>97	82	6								

Table A-1. Municipal Wastewater Removal Efficiencies for Full Scale Treatment Systems (Continued)

GENERAL CLASS KEY: NP/APEs - nonylphenols, octylphenol, and alkylphenol ethoxylate compounds; PAH - polynuclear aromatic hydrocarbons; PBDEs – polybrominated diphenyl ether fire retardants; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

		Phosphorus Removal (chemical)				Denitrification				Nitrification			
General Class	CEC	Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count
NP/APEs	4-(tert-octyl)phenol					>30	>96	82	6	>30	>96	79	8
NP/APEs	4-Nonylphenol					87	97	91	4	17	97	76	6
NP/APEs	Nonylphenol	88	93	90	4	57	90	83	5	57	90	83	5
NP/APEs	Nonylphenol diethoxylate	91	99	94	3	91	99	94	3	91	99	94	3
NP/APEs	Nonylphenol monoethoxylate	99	100	99	3	99	100	99	3	99	100	99	3
NP/APEs	Nonylphenoxyethoxyacetic acid	46	46	46	1	46	46	46	1	46	46	46	1
NP/APEs	Octylphenol	75	98	89	3	75	98	89	3	75	98	89	3
NP/APEs	Octylphenol diethoxylate	72	82	77	2	72	82	77	2	72	82	77	2
NP/APEs	Octylphenol monoethoxylate	76	98	88	3	76	98	88	3	76	98	88	3
Other	2,7-Dichlorodibenzo-p-dioxin												
Other	4-cumylphenol					81	81	81	1	81	81	81	1
Other	Bisphenol A	11	99	80	9	>37	>99	78	14	>37	>99	77	16
Other	Butylbenzyl phthalate	92	92	92	1	20	95	64	5	20	95	64	5
Other	Di(2-ethylhexyl)phthalate	93	93	93	1	18	93	58	3	18	93	58	3
Other	Dibutyl phthalate	88	88	88	1	83	92	88	3	83	92	88	3
Other	Diethyl phthalate	87	87	87	1	91	100	95	2	91	100	95	2
Other	Dimethyl phthalate	94	94	94	1	94	94	94	1	94	94	94	1
Other	Tri(chloroethyl) phosphate					4.5	4.5	4.5	1	4.5	4.5	4.5	1
Other	Triphenylphosphate												
PAH	Naphthalene	91	91	91	1								
PBDEs	PBDE-99	>58	>58	58	1								
pesticide	Chlorfenvinphos												
pesticide	DEET					>23	>84	54	2	>23	>84	54	2
pesticide	Permethrins-peak 1												
PPCP	1,7-Dimethylxanthine												
PPCP	2-Phenylphenol												
PPCP	3-Phenylpropionate					>70	>97	84	2	>70	>97	84	2
PPCP	4-Acetylsulfamethoxazole					90	91	90	2	91	91	91	1
PPCP	4-Chloro-m-cresol												
PPCP	Acebutolol					85	85	85	1	85	85	85	1
PPCP	Acetaminophen					98	98	98	1				
PPCP	Acetylsalicylic acid					>90	>90	90	1				
PPCP	Amoxicillin												
PPCP	Atenolol					<10	<84	61	4	71	84	78	2

GENERAL CLASS KEY: NP/APEs - nonylphenols, octylphenol, and alkylphenol ethoxylate compounds; PAH - polynuclear aromatic hydrocarbons; PBDEs – polybrominated diphenyl ether fire retardants; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

General Class	CEC	Phosphorus Removal (chemical)				Denitrification				Nitrification			
		Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count
PPCP	Azithromycin					39	39	39	1	39	39	39	1
PPCP	Benzophenone					>71	>90	81	2	>71	>90	81	2
PPCP	Benzyl salicylate					>94	>94	94	1	>94	>94	94	1
PPCP	Bezafibrate	35	100	78	9	35	100	81	10	35	100	85	9
PPCP	BHA												
PPCP	Biosol												
PPCP	Caffeine	100	100	100	3	>89	>100	94	2	>89	>100	94	2
PPCP	Carbamazepine	14	14	14	2	<10	<14	13	3	14	14	14	2
PPCP	Carbamazepine 10,11-epoxide												
PPCP	Cashmeran												
PPCP	Cefaclor												
PPCP	Celestolide	>41	>99	81	10								
PPCP	Celiprolol					36	36	36	1	36	36	36	1
PPCP	Cephalexin												
PPCP	Chloramphenicol												
PPCP	Chlorophene												
PPCP	Ciprofloxacin	64	64	64	1	89	89	89	1	59	89	74	2
PPCP	Clarithromycin					9.0	54	25	3	12	54	33	2
PPCP	Clofibric acid					28	52	40	2	52	52	52	1
PPCP	Codeine												
PPCP	Crotamiton												
PPCP	Diclofenac	>7.1	>99	58	21	9.7	63	43	10	9.7	63	43	9
PPCP	Dipyrone												
PPCP	Erythromycin-H2o					6.0	25	18	3	25	25	25	1
PPCP	Ethyl-3-phenylpropionate					>84	>84	84	1	>84	>84	84	1
PPCP	Gabapentin												
PPCP	Galaxolide	15	99	63	14	11	86	62	6	11	86	62	6
PPCP	Galaxolide-lactone												
PPCP	Gemfibrozil	>38	>99	83	11	>39	>90	64	2				
PPCP	Glibenclamide					45	45	45	1				
PPCP	Hydrochlorothiazide					76	76	76	1				
PPCP	Ibuprofen	>91	>100	98	23	>43	>100	91	13	>43	>100	92	11
PPCP	Indomethacin	>57	>99	89	8	23	23	23	1				
PPCP	Iohexol					89	89	89	1	89	89	89	1

Table A-1. Municipal Wastewater Removal Efficiencies for Full Scale Treatment Systems (Continued)

GENERAL CLASS KEY: NP/APEs - nonylphenols, octylphenol, and alkylphenol ethoxylate compounds; PAH - polynuclear aromatic hydrocarbons; PBDEs – polybrominated diphenyl ether fire retardants; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

General Class	CEC	Phosphorus Removal (chemical)				Denitrification				Nitrification			
		Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count
PPCP	Iomeprol					89	89	89	1	89	89	89	1
PPCP	iopamidol					17	17	17	1	17	17	17	1
PPCP	Iopromide	74	74	74	1	74	83	79	2	50	83	69	3
PPCP	Ketoprofen	>9.0	>99	78	8	52	80	66	2				
PPCP	Lincomycin												
PPCP	Mefenamic Acid					29	29	29	1				
PPCP	Methyl-3-phenylpropionate												
PPCP	Methylparaben					>93	>93	93	1	>93	>93	93	1
PPCP	Metoprolol					<10	<65	32	4	20	65	43	2
PPCP	Musk ketone												
PPCP	Musk xylene												
PPCP	Naproxen	>79	>100	95	15	85	85	85	1				
PPCP	Norfloxacin												
PPCP	Octylmethoxycinnamate					>39	>94	66	2	>39	>94	66	2
PPCP	Ofloxacin					24	24	24	1				
PPCP	Oxybenzone					>8.0	>91	50	2	>8.0	>91	50	2
PPCP	Paroxetine					91	91	91	1				
PPCP	p-Chloro-m-xylenol					>15	>98	57	2	>15	>98	57	2
PPCP	Penicillin V												
PPCP	Phantolide	>99	>99	99	4								
PPCP	Phenobarbital												
PPCP	Phenytoin												
PPCP	Pravastatin					62	62	62	1				
PPCP	Propranolol					28	65	47	2	65	65	65	1
PPCP	Propyphenazone					43	43	43	1				
PPCP	Ranitidine					42	42	42	1				
PPCP	Roxithromycin	41	88	58	3	21	88	43	6	21	88	45	5
PPCP	Sotalol					26	75	50	3	48	75	62	2
PPCP	Sulfadiazine												
PPCP	Sulfamethoxazole	66	75	70	2	9.0	66	43	5	24	76	56	4
PPCP	Sulfapyridine					61	61	61	1	61	61	61	1
PPCP	Sulfathiazole												
PPCP	Tetracycline	81	81	81	1					85	85	85	1
PPCP	Thymol												

Table A-1. Municipal Wastewater Removal Efficiencies for Full Scale Treatment Systems (Continued)

GENERAL CLASS KEY: NP/APEs - nonylphenols, octylphenol, and alkylphenol ethoxylate compounds; PAH - polynuclear aromatic hydrocarbons; PBDEs – polybrominated diphenyl ether fire retardants; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

General Class	CEC	Phosphorus Removal (chemical)				Denitrification				Nitrification			
		Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count
PPCP	Tonalide	>13	>99	67	15	70	97	84	5	70	97	84	5
PPCP	Traseolide	>9.0	>99	66	11								
PPCP	Triclocarban												
PPCP	Triclosan	>74	>99	94	15	>96	>96	96	1	>96	>96	96	1
PPCP	Trimethoprim	97	97	97	1	8.5	69	33	3	20	70	52	4
PPCP	Valproic acid												
S/H	17α-estradiol					63	63	63	1	63	63	63	1
S/H	Androsterone					99	100	99	2	99	100	99	2
S/H	Cholesterol												
S/H	Coprostanol												
S/H	Estradiol	>44	>99	93	23	>61	>97	87	14	>61	>97	88	16
S/H	Estriol	18	100	74	6	>28	>100	90	11	>28	>100	91	13
S/H	Estrogenic Activity												
S/H	Estrone	>3.0	>100	85	19	32	100	85	12	1.8	100	74	14
S/H	Ethinyl Estradiol	>25	>99	66	9	>25	>99	75	8	>25	>99	75	8
S/H	Etiocholanolone					92	98	95	2	92	98	95	2
S/H	Stigmasterol												
S/H	Testosterone					>88	>97	92	3	>51	>97	82	5

Table A-1. Municipal Wastewater Removal Efficiencies for Full Scale Treatment Systems (Continued)

GENERAL CLASS KEY: NP/APEs - nonylphenols, octylphenol, and alkylphenol ethoxylate compounds; PAH - polynuclear aromatic hydrocarbons; PBDEs – polybrominated diphenyl ether fire retardants; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

		Chlorine Disinfection				Granular Activated Carbon				Ozonation			
General Class	CEC	Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count
NP/APEs	4-(tert-octyl)phenol	50	97	87	8								
NP/APEs	4-Nonylphenol	17	94	73	8								
NP/APEs	Nonylphenol									82	89	85	2
NP/APEs	Nonylphenol diethoxylate	79	93	85	3								
NP/APEs	Nonylphenol monoethoxylate	45	74	58	3								
NP/APEs	Nonylphenoxyethoxyacetic acid												
NP/APEs	Octylphenol									58	84	71	2
NP/APEs	Octylphenol diethoxylate												
NP/APEs	Octylphenol monoethoxylate												
Other	2,7-Dichlorodibenzo-p-dioxin												
Other	4-cumylphenol												
Other	Bisphenol A	>20	>96	72	8	100	100	100	1	90	100	96	3
Other	Butylbenzyl phthalate	>20	>86	53	2								
Other	Di(2-ethylhexyl)phthalate												
Other	Dibutyl phthalate												
Other	Diethyl phthalate												
Other	Dimethyl phthalate												
Other	Tri(chloroethyl) phosphate	4.5	4.5	4.5	1								
Other	Triphenylphosphate												
PAH	Naphthalene												
PBDEs	PBDE-99												
pesticide	Chlorfenvinphos												
pesticide	DEET	23	23	23	1					69	79	74	2
pesticide	Permethrins-peak 1												
PPCP	1,7-Dimethylxanthine												
PPCP	2-Phenylphenol	89	89	89	1								
PPCP	3-Phenylpropionate	>70	>87	79	2								
PPCP	4-Acetylsulfamethoxazole												
PPCP	4-Chloro-m-cresol	>99	>99	99	1								
PPCP	Acebutolol												
PPCP	Acetaminophen	>90	>99	95	2								
PPCP	Acetylsalicylic acid	>90	>90	90	2					>90	>90	90	1
PPCP	Amoxicillin												
PPCP	Atenolol												

Table A-1. Municipal Wastewater Removal Efficiencies for Full Scale Treatment Systems (Continued)

GENERAL CLASS KEY: NP/APEs - nonylphenols, octylphenol, and alkylphenol ethoxylate compounds; PAH - polynuclear aromatic hydrocarbons; PBDEs – polybrominated diphenyl ether fire retardants; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

		Chlorine Disinfection				Granular Activated Carbon				Ozonation			
General Class	CEC	Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count
PPCP	Azithromycin									93	93	93	1
PPCP	Benzophenone	>71	>84	78	2								
PPCP	Benzyl salicylate	>96	>96	96	1								
PPCP	Bezafibrate												
PPCP	BHA												
PPCP	Biosol	>99	>99	99	1								
PPCP	Caffeine	>96	>100	98	2								
PPCP	Carbamazepine									60	60	60	1
PPCP	Carbamazepine 10,11-epoxide												
PPCP	Cashmeran												
PPCP	Cefaclor												
PPCP	Celestolide												
PPCP	Celiprolol												
PPCP	Cephalexin												
PPCP	Chloramphenicol	94	94	94	1								
PPCP	Chlorophene	73	73	73	1								
PPCP	Ciprofloxacin	71	71	71	1								
PPCP	Clarithromycin									91	91	91	1
PPCP	Clofibric acid												
PPCP	Codeine												
PPCP	Crotamiton									98	98	98	2
PPCP	Diclofenac	>18	>90	66	3								
PPCP	Dipyrone												
PPCP	Erythromycin-H2o									92	92	92	1
PPCP	Ethyl-3-phenylpropionate	>48	>84	66	2								
PPCP	Gabapentin	>99	>99	99	1								
PPCP	Galaxolide	11	99	57	4								
PPCP	Galaxolide-lactone	49	58	54	2								
PPCP	Gemfibrozil	>68	>90	83	3					>90	>90	90	1
PPCP	Glibenclamide												
PPCP	Hydrochlorothiazide												
PPCP	Ibuprofen	>43	>100	78	5					>90	>100	95	2
PPCP	Indomethacin												
PPCP	Iohexol												

Table A-1. Municipal Wastewater Removal Efficiencies for Full Scale Treatment Systems (Continued)

GENERAL CLASS KEY: NP/APEs - nonylphenols, octylphenol, and alkylphenol ethoxylate compounds; PAH - polynuclear aromatic hydrocarbons; PBDEs – polybrominated diphenyl ether fire retardants; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

		Chlorine Disinfection				Granular Activated Carbon				Ozonation			
General Class	CEC	Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count
PPCP	Iomeprol												
PPCP	iopamidol												
PPCP	Iopromide												
PPCP	Ketoprofen	77	94	83	4					69	95	81	3
PPCP	Lincomycin												
PPCP	Mefenamic Acid									54	54	54	1
PPCP	Methyl-3-phenylpropionate	>97	>97	97	1								
PPCP	Methylparaben	>91	>91	91	1								
PPCP	Metoprolol												
PPCP	Musk ketone	8.0	8.0	8.0	1								
PPCP	Musk xylene												
PPCP	Naproxen	>88	>100	93	3					>68	>100	84	2
PPCP	Norfloxacin												
PPCP	Octylmethoxycinnamate	>39	>96	67	2								
PPCP	Ofloxacin	98	98	98	1								
PPCP	Oxybenzone	>8.0	>95	51	2								
PPCP	Paroxetine												
PPCP	p-Chloro-m-xylenol	15	90	62	3								
PPCP	Penicillin V												
PPCP	Phantolide												
PPCP	Phenobarbital	>99	>99	99	1								
PPCP	Phenytoin	44	44	44	1								
PPCP	Pravastatin												
PPCP	Propranolol												
PPCP	Propyphenazone												
PPCP	Ranitidine												
PPCP	Roxithromycin									93	93	93	1
PPCP	Sotalol												
PPCP	Sulfadiazine	97	97	97	1								
PPCP	Sulfamethoxazole	47	98	73	2					96	96	96	1
PPCP	Sulfapyridine									95	95	95	1
PPCP	Sulfathiazole												
PPCP	Tetracycline	33	33	33	1								
PPCP	Thymol									>78	>91	85	2

Table A-1. Municipal Wastewater Removal Efficiencies for Full Scale Treatment Systems (Continued)

GENERAL CLASS KEY: NP/APEs - nonylphenols, octylphenol, and alkylphenol ethoxylate compounds; PAH - polynuclear aromatic hydrocarbons; PBDEs – polybrominated diphenyl ether fire retardants; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

General Class	CEC	Chlorine Disinfection				Granular Activated Carbon				Ozonation			
		Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count
PPCP	Tonalide	64	93	79	2								
PPCP	Traseolide												
PPCP	Triclocarban	97	97	97	1								
PPCP	Triclosan	>67	>99	83	4					99	100	99	2
PPCP	Trimethoprim	83	83	83	1					100	100	100	1
PPCP	Valproic acid	>99	>99	99	1								
S/H	17α-estradiol												
S/H	Androsterone												
S/H	Cholesterol												
S/H	Coprostanol												
S/H	Estradiol	>47	>96	78	8	100	100	100	1	100	100	100	2
S/H	Estriol	>95	>98	97	5					100	100	100	1
S/H	Estrogenic Activity												
S/H	Estrone	>0.87	>84	37	9	100	100	100	1	84	100	94	3
S/H	Ethinyl Estradiol	0.77	72	42	4								
S/H	Etiocholanolone												
S/H	Stigmasterol												
S/H	Testosterone	>51	>91	79	5								

Table A-1. Municipal Wastewater Removal Efficiencies for Full Scale Treatment Systems (Continued)

GENERAL CLASS KEY: NP/APEs - nonylphenols, octylphenol, and alkylphenol ethoxylate compounds; PAH - polynuclear aromatic hydrocarbons; PBDEs – polybrominated diphenyl ether fire retardants; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

General Class	CEC	Reverse Osmosis				Ultraviolet Disinfection			
		Min	Max	Avg	Count	Min	Max	Avg	Count
NP/APEs	4-(tert-octyl)phenol					>93	>97	95	4
NP/APEs	4-Nonylphenol	77	77	77	1	61	97	85	4
NP/APEs	Nonylphenol								
NP/APEs	Nonylphenol diethoxylate					79	79	79	1
NP/APEs	Nonylphenol monoethoxylate					74	74	74	1
NP/APEs	Nonylphenoxyethoxyacetic acid								
NP/APEs	Octylphenol					>99	>99	99	1
NP/APEs	Octylphenol diethoxylate								
NP/APEs	Octylphenol monoethoxylate								
Other	2,7-Dichlorodibenzo-p-dioxin								
Other	4-cumylphenol								
Other	Bisphenol A					>72	>92	85	4
Other	Butylbenzyl phthalate	>86	>86	86	1	>93	>95	94	3
Other	Di(2-ethylhexyl)phthalate								
Other	Dibutyl phthalate								
Other	Diethyl phthalate								
Other	Dimethyl phthalate								
Other	Tri(chloroethyl) phosphate					50	50	50	1
Other	Triphenylphosphate					57	57	57	1
PAH	Naphthalene								
PBDEs	PBDE-99								
pesticide	Chlorfenvinphos								
pesticide	DEET					>41	>84	64	3
pesticide	Permethrins-peak 1								
PPCP	1,7-Dimethylxanthine								
PPCP	2-Phenylphenol								
PPCP	3-Phenylpropionate	>87	>87	87	1	>94	>98	96	3
PPCP	4-Acetylsulfamethoxazole								
PPCP	4-Chloro-m-cresol								
PPCP	Acebutolol								
PPCP	Acetaminophen	>90	>90	90	1	>90	>90	90	1
PPCP	Acetylsalicylic acid	>90	>90	90	1	>90	>90	90	2
PPCP	Amoxicillin								

Table A-1. Municipal Wastewater Removal Efficiencies for Full Scale Treatment Systems (Continued)

GENERAL CLASS KEY: NP/APEs - nonylphenols, octylphenol, and alkylphenol ethoxylate compounds; PAH - polynuclear aromatic hydrocarbons; PBDEs – polybrominated diphenyl ether fire retardants; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

General Class	CEC	Reverse Osmosis				Ultraviolet Disinfection			
		Min	Max	Avg	Count	Min	Max	Avg	Count
PPCP	Atenolol								
PPCP	Azithromycin								
PPCP	Benzophenone	>84	>84	84	1	>89	>90	89	3
PPCP	Benzyl salicylate	>96	>96	96	1	>94	>98	96	3
PPCP	Bezafibrate								
PPCP	BHA					>92	>92	92	1
PPCP	Biosol								
PPCP	Caffeine	>96	>96	96	1	>89	>100	97	5
PPCP	Carbamazepine								
PPCP	Carbamazepine 10,11-epoxide								
PPCP	Cashmeran					54	54	54	1
PPCP	Cefaclor								
PPCP	Celestolide					50	50	50	1
PPCP	Celiprolol								
PPCP	Cephalexin								
PPCP	Chloramphenicol								
PPCP	Chlorophene								
PPCP	Ciprofloxacin					76	76	76	1
PPCP	Clarithromycin								
PPCP	Clofibric acid								
PPCP	Codeine								
PPCP	Crotamiton								
PPCP	Diclofenac	>90	>90	90	1	>86	>91	89	3
PPCP	Dipyrone								
PPCP	Erythromycin-H2o								
PPCP	Ethyl-3-phenylpropionate	>48	>48	48	1	>14	>81	48	2
PPCP	Gabapentin								
PPCP	Galaxolide	32	32	32	1	>13	>86	55	4
PPCP	Galaxolide-lactone								
PPCP	Gemfibrozil	>90	>90	90	1	>90	>90	90	2
PPCP	Glibenclamide								
PPCP	Hydrochlorothiazide								
PPCP	Ibuprofen	>72	>72	72	1	>81	>100	90	6

Table A-1. Municipal Wastewater Removal Efficiencies for Full Scale Treatment Systems (Continued)

GENERAL CLASS KEY: NP/APEs - nonylphenols, octylphenol, and alkylphenol ethoxylate compounds; PAH - polynuclear aromatic hydrocarbons; PBDEs – polybrominated diphenyl ether fire retardants; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

General Class	CEC	Reverse Osmosis				Ultraviolet Disinfection			
		Min	Max	Avg	Count	Min	Max	Avg	Count
PPCP	Indomethacin								
PPCP	Iohexol								
PPCP	Iomeprol								
PPCP	iopamidol								
PPCP	Iopromide								
PPCP	Ketoprofen	80	80	80	1	80	95	85	4
PPCP	Lincomycin								
PPCP	Mefenamic Acid								
PPCP	Methyl-3-phenylpropionate	>97	>97	97	1	>95	>95	95	1
PPCP	Methylparaben	>91	>91	91	1	>92	>93	92	3
PPCP	Metoprolol								
PPCP	Musk ketone	8.0	8.0	8.0	1	42	85	64	2
PPCP	Musk xylene					53	53	53	1
PPCP	Naproxen	>90	>90	90	1	>90	>100	97	3
PPCP	Norfloxacin								
PPCP	Octylmethoxycinnamate	>96	>96	96	1	>94	>99	97	3
PPCP	Ofloxacin								
PPCP	Oxybenzone	>95	>95	95	1	>89	>96	92	3
PPCP	Paroxetine								
PPCP	p-Chloro-m-xylenol	90	90	90	1	>93	>98	96	3
PPCP	Penicillin V								
PPCP	Phantolide					44	44	44	1
PPCP	Phenobarbital								
PPCP	Phenytoin								
PPCP	Pravastatin								
PPCP	Propranolol								
PPCP	Propyphenazone								
PPCP	Ranitidine								
PPCP	Roxithromycin								
PPCP	Sotalol								
PPCP	Sulfadiazine								
PPCP	Sulfamethoxazole					33	33	33	1
PPCP	Sulfapyridine								

Table A-1. Municipal Wastewater Removal Efficiencies for Full Scale Treatment Systems (Continued)

GENERAL CLASS KEY: NP/APEs - nonylphenols, octylphenol, and alkylphenol ethoxylate compounds; PAH - polynuclear aromatic hydrocarbons; PBDEs – polybrominated diphenyl ether fire retardants; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

General Class	CEC	Reverse Osmosis				Ultraviolet Disinfection			
		Min	Max	Avg	Count	Min	Max	Avg	Count
PPCP	Sulfathiazole								
PPCP	Tetracycline					64	64	64	1
PPCP	Thymol								
PPCP	Tonalide					52	52	52	1
PPCP	Traseolide					58	58	58	1
PPCP	Triclocarban								
PPCP	Triclosan	>67	>67	67	1	>71	>99	90	5
PPCP	Trimethoprim					77	77	77	1
PPCP	Valproic acid								
S/H	17α-estradiol								
S/H	Androsterone								
S/H	Cholesterol					85	85	85	1
S/H	Coprostanol					97	97	97	1
S/H	Estradiol					>61	>98	76	3
S/H	Estriol					>90	>100	96	3
S/H	Estrogenic Activity								
S/H	Estrone	>84	>84	84	1	22	96	74	4
S/H	Ethinyl Estradiol					0.77	0.77	0.77	1
S/H	Etiocholanolone								
S/H	Stigmasterol					98	98	98	1
S/H	Testosterone					97	97	97	1

Table A-2. Municipal Wastewater Removal Efficiencies for Pilot Scale Treatment Systems

GENERAL CLASS KEY: NP/APEs - nonylphenols, octylphenol, and alkylphenol ethoxylate compounds; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

General Class	CEC	Activated Sludge				Denitrification				Nitrification				Reverse Osmosis				Ultraviolet Disinfection			
		Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count
NP/APEs	Nonylphenol	91	94	92	2	85	91	88	3	85	91	88	3								
NP/APEs	Nonylphenol diethoxylate					85	94	91	3	85	94	91	3								
NP/APEs	Nonylphenol monoethoxylate	69	75	72	2	97	99	98	3	97	99	98	3								
NP/APEs	Nonylphenol n-ethoxylate	98	99	99	2																
NP/APEs	Nonylphenol triethoxylate	6.4	6.4	6.4	1																
NP/APEs	Octylphenol					45	98	69	3	45	98	69	3								
NP/APEs	Octylphenol diethoxylate					58	82	70	2	58	82	70	2								
NP/APEs	Octylphenol monoethoxylate					76	98	88	3	76	98	88	3								
Other	Bisphenol A					93	99	97	6	93	99	97	6								
Other	Butylbenzyl phthalate					>96	>97	96	2	>96	>97	96	2								
Other	Tri(chloroethyl) phosphate													>90	>95	93	4	91	95	93	2
pesticide	DEET					>84	>84	84	1	>84	>84	84	1	>94	>100	97	4	>94	>94	94	2
PPCP	3-Phenylpropionate					>97	>98	98	2	>97	>98	98	2								
PPCP	Acetaminophen													>99	>100	100	4	>100	>100	100	2
PPCP	Benzophenone					>88	>99	94	2	>88	>99	94	2								
PPCP	Benzyl salicylate					>94	>98	96	2	>94	>98	96	2								
PPCP	Bezafibrate					77	96	89	6	77	96	89	6								
PPCP	BHA					>78	>78	78	1	>78	>78	78	1								
PPCP	Caffeine					>89	>99	94	2	>89	>99	94	2	>100	>100	100	4	>100	>100	100	2
PPCP	Carbamazepine					4.4	12	8.5	4	4.4	12	8.5	4	>98	>100	99	4	>98	>98	98	2
PPCP	Diclofenac					33	51	42	4	33	51	42	4	>90	>97	93	4	>90	>90	90	2
PPCP	Dilantin													>100	>100	100	2				
PPCP	Erythromycin-H2o													>97	>98	98	4	>98	>98	98	2
PPCP	Ethyl-3-phenylpropionate					>74	>74	74	1	>74	>74	74	1								
PPCP	Fluoxetine													>93	>94	94	2				
PPCP	Galaxolide					46	92	75	5	46	92	75	5								
PPCP	Gemfibrozil													>100	>100	100	2				
PPCP	Hydrocodone													>90	>99	94	4	90	90	90	2
PPCP	Ibuprofen					>85	>99	96	8	>85	>99	96	8	>100	>100	100	4	>100	>100	100	2
PPCP	Iopromide													>100	>100	100	2				
PPCP	Meprobamate													>100	>100	100	2				

Table A-2. Municipal Wastewater Removal Efficiencies for Pilot Scale Treatment Systems (Continued)

GENERAL CLASS KEY: NP/APEs - nonylphenols, octylphenol, and alkylphenol ethoxylate compounds; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

General Class	CEC	Activated Sludge				Denitrification				Nitrification				Reverse Osmosis				Ultraviolet Disinfection			
		Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count
PPCP	Methylparaben					>93	>93	93	2	>93	>93	93	2								
PPCP	Musk ketone					38	38	38	1	38	38	38	1								
PPCP	Naproxen													>100	>100	100	4	>100	>100	100	2
PPCP	Octylmethoxycinnamate					>94	>98	96	2	>94	>98	96	2								
PPCP	Oxybenzone					>91	>97	94	2	>91	>97	94	2	>97	>98	97	4	>97	>97	97	2
PPCP	p-Chloro-m-xylenol					>98	>99	99	2	>98	>99	99	2								
PPCP	Roxithromycin					34	74	56	3	34	74	56	3								
PPCP	Sulfamethoxazole					61	61	61	1	61	61	61	1	>99	>100	100	4	>99	>99	99	2
PPCP	Tonalide					85	91	87	3	85	91	87	3								
PPCP	Triclosan					>89	>96	93	2	>89	>96	93	2	>98	>99	98	4	>99	>99	99	2
PPCP	Trimethoprim													>95	>99	97	4	>95	>95	95	2
S/H	Androstenedione	98	99	99	2									>96	>99	98	4	>99	>99	99	2
S/H	Estradiol	93	98	96	2	>92	>96	94	4	>92	>96	94	4	>88	>94	91	2				
S/H	Estriol	65	65	65	1	100	100	100	3	100	100	100	3	>98	>98	98	2	>98	>98	98	2
S/H	Estrone	51	58	54	2	28	99	78	4	28	99	78	4	>99	>99	99	2				
S/H	Ethinyl Estradiol	48	76	62	2	>33	>80	62	4	>33	>80	62	4	>80	>97	88	2				
S/H	Progesterone	96	97	97	2									>80	>84	82	2				
S/H	Testosterone	98	99	99	2									>98	>98	98	2	>98	>98	98	2

Table A-3. Municipal Wastewater Removal Efficiencies for Lab Scale Treatment Systems

GENERAL CLASS KEY: PPCP - pharmaceuticals and personal care products																									
		Activated Sludge				**Phosphorus Removal (biological)**				**Denitrification**				**Granular Activated Carbon**				**Ozonation**				**Ultraviolet Disinfection**			
General Class	**CEC**	**Min**	**Max**	**Avg**	**Count**	**Min**	**Max**	**Avg**	**Count**	**Min**	**Max**	**Avg**	**Count**	**Min**	**Max**	**Avg**	**Count**	**Min**	**Max**	**Avg**	**Count**	**Min**	**Max**	**Avg**	**Count**
PPCP	Atenolol	29	71	43	5					36	36	36	1												
PPCP	Bezafibrate	>98	>98	98	1									>98	>98	98	1	>98	>98	98	1				
PPCP	Carbamazepine	>97	>97	97	1									>97	>97	97	1	>95	>99	97	3	95	95	95	1
PPCP	Chloramphenicol	89	100	96	9	89	100	96	9	89	100	96	9												
PPCP	Clofibric acid																	88	99	94	2	99	99	99	1
PPCP	Diazepam																	90	95	93	2	90	90	90	1
PPCP	Diclofenac	>49	>97	68	3									>97	>97	97	1	>97	>100	99	3	100	100	100	1
PPCP	Ibuprofen	91	92	91	2																				
PPCP	Ketoprofen	90	91	90	2																				
PPCP	Lincomycin	69	69	69	1																				
PPCP	Naproxen	87	94	90	2																				
PPCP	Ranitidine	17	29	23	6					17	25	21	2												
PPCP	Tetracycline	50	86	75	5																				

Table A-4. Drinking Water Removal Efficiencies for Full Scale Treatment Systems

GENERAL CLASS KEY: PAH - polynuclear aromatic hydrocarbons; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

		Chlorine Disinfection				Granular Activated Carbon				Ozonation				Ultraviolet Disinfection			
General Class	CEC	Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count
Other	Tri(chloroethyl) phosphate	>8.6	>85	45	6									5.3	5.3	5.3	1
PAH	Fluorene	>23	>88	55	2												
pesticide	Atrazine	3.5	99	22	6	99	99	99	1					3.6	3.6	3.6	1
pesticide	DEET	>2.4	>75	21	9	>75	>75	75	1					19	22	21	2
pesticide	Metolachlor	>8.0	>92	32	4	>92	>92	92	1								
PPCP	Acetaminophen	>9.1	>89	43	6									>44	>44	44	1
PPCP	Caffeine	>7.4	>67	29	9									42	42	42	1
PPCP	Carbamazepine	>2.6	>85	49	10	>60	>85	72	2					>17	>17	17	1
PPCP	Clofibric acid	99	99	99	1					99	99	99	1				
PPCP	Dilantin	>7.7	>48	27	7	>29	>29	29	1					15	15	15	1
PPCP	Erythromycin-H2o	>29	>69	56	4	>29	>29	29	1								
PPCP	Galaxolide	>11	>11	11	1									>8.3	>23	14	3
PPCP	Gemfibrozil	>1.9	>83	44	9	>79	>79	79	1					69	69	69	1
PPCP	Hydrocodone	>47	>47	47	1												
PPCP	Ibuprofen	>5.0	>58	31	6	>58	>58	58	1								
PPCP	Iopromide	8.3	65	30	7	45	45	45	1								
PPCP	Meprobamate	>5.0	>50	23	4	>50	>50	50	1								
PPCP	Musk ketone	>29	>29	29	1												
PPCP	Naproxen	>9.1	>100	60	10	>47	>47	47	1	99	99	99	1				
PPCP	Oxybenzone	>33	>86	65	3												
PPCP	Sulfamethoxazole	>13	>98	69	12	>17	>67	42	2					>83	>83	83	1
PPCP	Triclosan	>9.1	>63	42	4												
PPCP	Trimethoprim	>55	>57	56	2												
S/H	Androstenedione	>47	>47	47	1												

Table A-5. Drinking Water Removal Efficiencies for Pilot Scale Treatment Systems

GENERAL CLASS KEY: PPCP - pharmaceuticals and personal care products					
		Ozonation			
General Class	**CEC**	**Min**	**Max**	**Avg**	**Count**
PPCP	Clofibric acid	99	99	99	1
PPCP	Naproxen	99	99	99	1

Table A-6. Drinking Water Removal Efficiencies for Lab Scale Treatment Systems

GENERAL CLASS KEY: PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones									
		Chlorine Disinfection				**Granular Activated Carbon**			
General Class	**CEC**	**Min**	**Max**	**Avg**	**Count**	**Min**	**Max**	**Avg**	**Count**
PPCP	Caffeine	>8.1	>94	51	2	>94	>94	94	1
PPCP	Salicylic acid	>35	>49	42	2	>49	>49	49	1
PPCP	Trovafloxacin	>26	>95	60	2	>95	>95	95	1
S/H	Estradiol	>9.2	>95	52	2	>95	>95	95	1

Table A-7. Treated Wastewater Removal Efficiencies for Full Scale Treatment Systems

GENERAL CLASS KEY: NP/APEs - nonylphenols, octylphenol, and alkylphenol ethoxylate compounds; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

General Class	CEC	Activated Sludge				Fixed Film Biological Treatment				Chlorine Disinfection				Granular Activated Carbon			
		Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count
NP/APEs	Nonylphenol																
NP/APEs	Octylphenol																
Other	Bisphenol A																
Other	N-BBSA																
Other	Tri(chloroethyl) phosphate	6.5	6.5	6.5	1					6.5	6.5	6.5	1				
pesticide	Atrazine													3.0	3.0	3.0	1
pesticide	DEET	>17	>74	46	2					>17	>74	46	2	63	63	63	1
pesticide	Metolachlor													>71	>71	71	1
PPCP	Acetaminophen	65	65	65	1					>65	>90	77	2	19	100	59	2
PPCP	Acetylsalicylic acid									>90	>90	90	1				
PPCP	Atenolol					1.0	1.0	1.0	1								
PPCP	BHA																
PPCP	BHT																
PPCP	Caffeine	2.6	48	30	3					40	48	44	2	5.6	16	11	2
PPCP	Carbamazepine	3.5	40	22	2	6.0	6.0	6.0	1	>40	>90	65	2	1.0	16	8.3	2
PPCP	Carisoprodol																
PPCP	Cefaclor																
PPCP	Cephalexin																
PPCP	Chlortetracycline																
PPCP	Ciprofloxacin																
PPCP	Clofibric acid																
PPCP	Crotamiton																
PPCP	Diazepam	32	32	32	1					32	32	32	1				
PPCP	Diclofenac	>18	>82	47	3					>41	>82	61	2	>50	>69	59	2
PPCP	Dilantin	>11	>80	45	2					>11	>80	45	2	4.5	23	14	2
PPCP	Enrofloxacin																
PPCP	Erythromycin-H2o	>99	>99	99	1					>99	>99	99	1	7.9	7.9	7.9	1
PPCP	Fenofibrate																
PPCP	Fenoprofen																
PPCP	Fluoxetine	>5.3	>97	46	3					>35	>97	66	2				
PPCP	Galaxolide																
PPCP	Gemfibrozil	59	92	75	2					>59	>92	80	3	4.0	8.2	6.1	2

Table A-7. Treated Wastewater Removal Efficiencies for Full Scale Treatment Systems (Continued)

GENERAL CLASS KEY: NP/APEs - nonylphenols, octylphenol, and alkylphenol ethoxylate compounds; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

		Activated Sludge				Fixed Film Biological Treatment				Chlorine Disinfection				Granular Activated Carbon			
General Class	CEC	Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count
PPCP	Hydrocodone	>5.2	>98	38	3					>5.2	>98	52	2	>14	>56	35	2
PPCP	Ibuprofen	5.6	50	28	2					>5.6	>90	49	3	16	16	16	1
PPCP	Iopromide	55	55	55	1					55	55	55	1	18	72	45	2
PPCP	Ketoprofen									80	80	80	2				
PPCP	Lincomycin																
PPCP	Mefenamic Acid																
PPCP	Meprobamate	11	11	11	1					11	11	11	1	6.2	13	9.7	2
PPCP	Metoprolol					5.0	5.0	5.0	1								
PPCP	Monensin																
PPCP	Musk ketone																
PPCP	Nalidixic Acid																
PPCP	Naproxen	>98	>98	98	1					>98	>100	99	2	0.85	6.3	3.6	2
PPCP	Norfloxacin																
PPCP	Norfluoxetine																
PPCP	Oleandomycin																
PPCP	Oxybenzone	>67	>92	80	2					>67	>92	80	2				
PPCP	Pentoxifylline	>20	>72	46	2					>20	>72	46	2	>12	>26	19	2
PPCP	Primidone									89	89	89	1				
PPCP	Propyphenazone																
PPCP	p-TSA																
PPCP	Roxithromycin																
PPCP	Salinomycin																
PPCP	Sulfamethoxazole	>25	>93	49	3					>29	>93	61	2	15	84	49	2
PPCP	Sulphasalazine																
PPCP	Thymol																
PPCP	Triclosan	>79	>79	79	1					>79	>79	79	1	47	47	47	1
PPCP	Trimethoprim	>12	>98	68	3					>95	>98	96	2	4.8	64	35	2
PPCP	Tylosin																
S/H	Androstenedione													1.1	61	31	2
S/H	Estradiol																
S/H	Estriol	27	48	35	3					27	48	37	2	7.2	7.2	7.2	1
S/H	Estrone	>58	>90	74	2					90	90	90	1				
S/H	Testosterone	13	13	13	1					13	13	13	1	9.3	74	42	2

Table A-7. Treated Wastewater Removal Efficiencies for Full Scale Treatment Systems (Continued)

GENERAL CLASS KEY: NP/APEs - nonylphenols, octylphenol, and alkylphenol ethoxylate compounds; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

		Ozonation				Reverse Osmosis				Ultrafiltration				Ultraviolet Disinfection			
General Class	CEC	Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count
NP/APEs	Nonylphenol	42	100	71	2												
NP/APEs	Octylphenol	100	100	100	1												
Other	Bisphenol A	76	100	86	3					76	76	76	1				
Other	N-BBSA					99	100	100	3								
Other	Tri(chloroethyl) phosphate					>97	>98	97	2								
pesticide	Atrazine	>7.7	>47	28	3					7.7	7.7	7.7	1				
pesticide	DEET	>48	>100	67	5	>50	>100	83	3					50	50	50	1
pesticide	Metolachlor													>71	>71	71	1
PPCP	Acetaminophen					>90	>94	92	2					19	19	19	1
PPCP	Acetylsalicylic acid					>90	>90	90	1								
PPCP	Atenolol	100	100	100	1					100	100	100	1				
PPCP	BHA					90	100	96	3								
PPCP	BHT					100	100	100	3								
PPCP	Caffeine	95	95	95	1	>96	>100	99	5					2.6	5.6	4.1	2
PPCP	Carbamazepine	>71	>100	88	6	>90	>100	98	6	>100	>100	100	1	1.0	3.5	2.3	2
PPCP	Carisoprodol					100	100	100	3								
PPCP	Cefaclor					74	74	74	1								
PPCP	Cephalexin					85	85	85	1								
PPCP	Chlortetracycline					10	10	10	1								
PPCP	Ciprofloxacin					98	98	98	1								
PPCP	Clofibric acid					90	100	96	3								
PPCP	Crotamiton	>100	>100	100	2												
PPCP	Diazepam	>84	>84	84	1					>84	>84	84	1				
PPCP	Diclofenac	>100	>100	100	1	>98	>98	98	2	>100	>100	100	1	18	50	34	2
PPCP	Dilantin	52	89	63	4	>99	>100	99	2	89	89	89	1	4.5	4.5	4.5	1
PPCP	Enrofloxacin					75	75	75	1								
PPCP	Erythromycin-H2o	>60	>60	60	1	>99	>100	100	2								
PPCP	Fenofibrate					100	100	100	1								
PPCP	Fenoprofen	1.4	1.4	1.4	1												
PPCP	Fluoxetine	>99	>99	99	1	>92	>92	92	1	>99	>99	99	1	5.3	5.3	5.3	1
PPCP	Galaxolide	55	55	55	1	>99	>99	99	1								
PPCP	Gemfibrozil	>50	>99	76	3	>47	>100	90	6	>99	>99	99	1	>4.0	>47	26	2
PPCP	Hydrocodone					>98	>98	98	2					11	14	12	2
PPCP	Ibuprofen	>41	>100	73	4	>90	>100	97	5								
PPCP	Iopromide	25	50	38	2	>99	>100	100	2					18	18	18	1

Table A-7. Treated Wastewater Removal Efficiencies for Full Scale Treatment Systems (Continued)

GENERAL CLASS KEY: NP/APEs - nonylphenols, octylphenol, and alkylphenol ethoxylate compounds; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

		Ozonation				Reverse Osmosis				Ultrafiltration				Ultraviolet Disinfection			
General Class	CEC	Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count
PPCP	Ketoprofen	72	100	86	2	80	80	80	2								
PPCP	Lincomycin					90	90	90	1								
PPCP	Mefenamic Acid	>64	>99	82	2												
PPCP	Meprobamate	25	70	38	4	>100	>100	100	2	70	70	70	1	6.2	6.2	6.2	1
PPCP	Metoprolol																
PPCP	Monensin					98	98	98	1								
PPCP	Musk ketone					>84	>84	84	1								
PPCP	Nalidixic Acid					86	86	86	1								
PPCP	Naproxen	>92	>100	97	4	>100	>100	100	3	>98	>98	98	1	0.85	0.85	0.85	1
PPCP	Norfloxacin					97	97	97	1								
PPCP	Norfluoxetine	>69	>69	69	1					>69	>69	69	1				
PPCP	Oleandomycin					75	75	75	1								
PPCP	Oxybenzone					>63	>98	86	3					63	63	63	1
PPCP	Pentoxifylline					>97	>99	98	2					12	12	12	1
PPCP	Primidone					89	89	89	1								
PPCP	Propyphenazone	>59	>59	59	1												
PPCP	p-TSA					100	100	100	3								
PPCP	Roxithromycin					93	93	93	1								
PPCP	Salinomycin					80	80	80	1								
PPCP	Sulfamethoxazole	>90	>99	93	4	>44	>100	81	3	99	99	99	1	>15	>44	28	3
PPCP	Sulphasalazine					88	88	88	1								
PPCP	Thymol	87	97	92	2												
PPCP	Triclosan	>69	>100	89	4	>99	>100	100	2	>98	>98	98	1	47	47	47	1
PPCP	Trimethoprim	97	97	97	1	>94	>100	98	3	97	97	97	1	4.8	12	8.4	2
PPCP	Tylosin					95	95	95	1								
S/H	Androstenedione													1.1	1.1	1.1	1
S/H	Estradiol	>93	>97	95	2	>88	>98	93	5								
S/H	Estriol	>55	>78	66	2	>67	>98	85	4					7.2	30	19	2
S/H	Estrone	>29	>100	76	3	>99	>99	99	2					>58	>58	58	1
S/H	Testosterone					>92	>100	96	5					9.3	9.3	9.3	1

Table A-8. Treated Wastewater Removal Efficiencies for Pilot Scale Treatment Systems

GENERAL CLASS KEY: PAH - polynuclear aromatic hydrocarbons; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

General Class	CEC	Ozonation				Reverse Osmosis				Ultrafiltration			
		Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count
Other	Bisphenol A	72	86	80	3								
Other	N-BBSA					100	100	100	1				
Other	Tri(chloroethyl) phosphate	<1.0	<18	8.6	8	96	99	98	3	7.7	99	53	2
PAH	Benzo[a]pyrene									>89	>89	89	1
PAH	Fluorene									>74	>74	74	1
pesticide	Atrazine									15	15	15	1
pesticide	DDT, p, p-									>85	>85	85	1
pesticide	DEET	42	98	83	9	>97	>99	98	3	>8.4	>99	54	2
pesticide	Lindane									>85	>85	85	1
pesticide	Metolachlor									56	56	56	1
PPCP	Acebutolol	>92	>92	92	1								
PPCP	Acetaminophen					>60	>100	85	3	5.6	95	50	2
PPCP	Atenolol	>61	>86	77	4								
PPCP	Benzophenone	>50	>60	57	3								
PPCP	Bezafibrate	>77	>77	77	1								
PPCP	BHA					95	95	95	1				
PPCP	Caffeine	>34	>80	70	12	<91	>100	97	3	<7.1	<91	49	2
PPCP	Carbamazepine	>68	>100	97	13	>95	>100	98	4	>16	>99	57	2
PPCP	Carisoprodol					100	100	100	1				
PPCP	Celiprolol	82	82	82	3								
PPCP	Ciprofloxacin	16	16	16	1								
PPCP	Clarithromycin	76	76	76	3								
PPCP	Clofibric acid	50	58	56	3	100	100	100	1				
PPCP	Diatrizoate	13	14	14	2								
PPCP	Diazepam					>9.1	>9.1	9.1	1	84	84	84	1
PPCP	Diclofenac	>94	>99	97	13	>82	>95	89	2	2.6	95	49	2
PPCP	Dilantin	>43	>100	87	9	>95	>99	98	3	>25	>99	62	2
PPCP	Erythromycin anhydrate	>92	>99	95	6								
PPCP	Erythromycin-H2o	>99	>100	100	6	>89	>100	95	2	>15	>100	57	2
PPCP	Fenofibrate					100	100	100	1				
PPCP	Fenofibric Acid	54	62	59	3								
PPCP	Fluoxetine	>93	>99	95	6	>77	>95	87	3	69	95	82	2

Table A-8. Treated Wastewater Removal Efficiencies for Pilot Scale Treatment Systems (Continued)

GENERAL CLASS KEY: PAH - polynuclear aromatic hydrocarbons; PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category

		Ozonation				Reverse Osmosis				Ultrafiltration			
General Class	CEC	Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count
PPCP	Galaxolide	>88	>100	96	9	>98	>99	99	2	>99	>99	99	1
PPCP	Gemfibrozil	>94	>99	96	3	>99	>100	99	2	>99	>99	99	1
PPCP	Hydrocodone	>93	>100	99	9	>97	>99	98	2	>14	>99	57	2
PPCP	Ibuprofen	<1.0	>99	74	13	>83	>100	94	3	7.7	7.7	7.7	1
PPCP	Indomethacin	50	50	50	3								
PPCP	Iomeprol	34	90	66	3								
PPCP	Iopamidol	33	84	58	3								
PPCP	Iopromide	>14	>96	73	12	<95	>98	96	2	<95	<95	95	1
PPCP	Isobutylparaben	74	91	82	3								
PPCP	Ketoprofen	>62	>62	62	1								
PPCP	Meprobamate	>31	>98	69	9	>99	>100	99	3	>5.7	>100	53	2
PPCP	Metoprolol	>78	>97	92	4								
PPCP	Musk ketone	37	68	51	6	>85	>90	87	2	>37	>90	63	2
PPCP	Naproxen	>50	>96	76	10	>95	>100	97	2	13	95	54	2
PPCP	Oxybenzone	<1.0	>83	53	3	>83	>99	93	3	>84	>98	91	2
PPCP	Pentoxifylline					>86	>86	86	1	10	10	10	1
PPCP	Propranolol	72	72	72	3								
PPCP	Propylparaben	>87	>94	89	3								
PPCP	p-TSA					100	100	100	1				
PPCP	Roxithromycin	91	91	91	3								
PPCP	Sotalol	>96	>96	96	4								
PPCP	Sulfamethoxazole	>92	>100	97	12	>99	>99	99	2	4.5	99	52	2
PPCP	Tonalide	50	50	50	3								
PPCP	Triclocarban	99	100	99	3								
PPCP	Triclosan	>95	>99	97	3	>17	>99	71	3	>88	>97	92	2
PPCP	Trimethoprim	>85	>99	94	12	>99	>99	99	2	>18	>99	59	2
S/H	3-Indolebutyric acid	83	85	84	3								
S/H	Androstenedione	>39	>58	45	3	>83	>98	91	2	71	71	71	1
S/H	Estradiol									>99	>99	99	1
S/H	Estriol					>99	>99	99	1	41	41	41	1
S/H	Estrone	<1.0	>91	69	6	>97	>97	97	2	>91	>97	94	2
S/H	Ethinyl Estradiol									>99	>99	99	1
S/H	Hydrocortisone	>93	>93	93	3								
S/H	Progesterone					>95	>95	95	1	>98	>98	98	1
S/H	Testosterone	>44	>98	62	3	>96	>96	96	1	72	72	72	1

Table A-9. Treated Wastewater Removal Efficiencies for Lab Scale Treatment Systems

GENERAL CLASS KEY: PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category													
General Class	**CEC**	**Chlorine Disinfection**				**Granular Activated Carbon**				**Ozonation**			
		Min	**Max**	**Avg**	**Count**	**Min**	**Max**	**Avg**	**Count**	**Min**	**Max**	**Avg**	**Count**
Other	Bisphenol A												
Other	Bisphenol F												
Other	TCIPP												
Other	TDCPP												
Other	Tri(chloroethyl) phosphate												
Other	Triethylene glycol dimethacrylate												
pesticide	Alachlor												
pesticide	Atraton												
pesticide	DEET												
pesticide	Metolachlor												
PPCP	Acetaminophen												
PPCP	Caffeine												
PPCP	Carbadox												
PPCP	Carbamazepine									92	99	97	4
PPCP	Clofibric acid									89	98	94	4
PPCP	Diazepam									53	88	71	4
PPCP	Diclofenac									100	100	100	4
PPCP	Diethylstilbestrol												
PPCP	Gemfibrozil												
PPCP	oxybenzone												
PPCP	Primidone												
PPCP	Sulfachloropyridazine												
PPCP	Sulfamerazine												
PPCP	Sulfamethizole												
PPCP	sulfamethoxazole												
S/H	17α-estradiol												
S/H	Equilin												
S/H	Estradiol	29	29	29	1					80	100	90	2
S/H	Estriol	27	27	27	1								
S/H	Estrone	27	27	27	1								
S/H	Ethinyl Estradiol	30	30	30	1	96	99	98	3				

Table A-9. Fully- or Partially-Treated Wastewater Removals Across Lab Scale Treatment Systems (Continued)

GENERAL CLASS KEY: PPCP - pharmaceuticals and personal care products; S/H - steroids and hormones; Other - category for analytes that do not fit into another category													
General Class	CEC	Reverse Osmosis				Ultrafiltration				Ultraviolet Disinfection			
		Min	Max	Avg	Count	Min	Max	Avg	Count	Min	Max	Avg	Count
Other	Bisphenol A	14	85	50	3	58	96	77	2				
Other	Bisphenol F	54	54	54	1	9.7	9.7	9.7	1				
Other	TCIPP	98	98	98	1								
Other	TDCPP	89	89	89	1								
Other	Tri(chloroethyl) phosphate	94	94	94	1								
Other	Triethylene glycol dimethacrylate	19	19	19	1	40	40	40	1				
pesticide	Alachlor	6.0	6.0	6.0	1	89	89	89	1				
pesticide	Atraton	5.0	5.0	5.0	1	43	43	43	1				
pesticide	DEET					60	60	60	1				
pesticide	Metolachlor	14	14	14	1	86	86	86	1				
PPCP	Acetaminophen	7.0	7.0	7.0	1	20	20	20	1				
PPCP	Caffeine	5.0	5.0	5.0	1	4.0	4.0	4.0	1				
PPCP	Carbadox	35	35	35	1	22	22	22	1				
PPCP	Carbamazepine	10	10	10	1	19	19	19	1	92	99	96	2
PPCP	Clofibric acid									97	98	98	2
PPCP	Diazepam									77	88	83	2
PPCP	Diclofenac									100	100	100	2
PPCP	Diethylstilbestrol	65	65	65	1	99	99	99	1				
PPCP	Gemfibrozil	21	21	21	1	60	60	60	1				
PPCP	oxybenzone	33	33	33	1	100	100	100	1				
PPCP	Primidone	98	98	98	1								
PPCP	Sulfachloropyridazine	12	12	12	1	5.0	5.0	5.0	1				
PPCP	Sulfamerazine	19	19	19	1	25	25	25	1				
PPCP	Sulfamethizole	17	17	17	1	11	11	11	1				
PPCP	sulfamethoxazole	12	12	12	1	23	23	23	1				
S/H	17α-estradiol	23	23	23	1	96	96	96	1				
S/H	Equilin	31	31	31	1	97	97	97	1				
S/H	Estradiol	38	38	38	1	99	99	99	1				
S/H	Estriol					32	32	32	1				
S/H	Estrone	19	19	19	1	98	98	98	1				
S/H	Ethinyl Estradiol	19	19	19	1	95	95	95	1				

Appendix B

CECS REMOVALS DATABASE USERS GUIDE

Contaminants of Emerging Concern (CECs) Removals Database Version 3 User's Guide
For the Non-Access®-Trained User

The *CECs Removals Database* is a Microsoft Access® database designed to store and manage information from published scientific studies of the removal of contaminants of emerging concern (CECs) from water and wastewater. The database captures bibliographic information about the published study as well as information about the CECs studied, the treatment technologies employed, the types of water/waste treated, and the performance of the studied treatment systems and unit operations. Engineers reviewed the published studies and entered influent, effluent, and intermediate concentration data or percent removals into the database. You can use the database to calculate the average percent removal for studied CECs.

The database contains a simple-to-use form that helps you select the types of studies to include in the calculated average percent removal.

Terms Used on the Quick Search

Treatment Technology – A unit operation or treatment step employed in a water or wastewater treatment system. Examples of treatment technologies are: settling tanks, activated sludge treatment, chlorine disinfection.

Unit Process – A basic, single step of a water or wastewater treatment process. For example, settling tank, media filter, or activated carbon.

Treatment System – Water or wastewater treatment process, usually involving two or more treatment technologies/unit processes operated in sequence. For example, a traditional wastewater treatment plant may include settling tanks, followed by activated sludge treatment with nitrification and denitrification, and finally followed by chlorine disinfection. These unit processes, operated together in sequence, make up a treatment system.

Scale – Describes the scale of the studied water or wastewater treatment operation. "Full scale" indicates that the studied operation was used in a real-world application treating water or waste, and samples were collected during normal operation with continuous flow. "Pilot scale" indicates that the studied operation was run as an experimental unit using real water or waste collected from a full-scale system, and flow through the system was continuous. "Lab scale" indicates that the studied operation was run as a bench test in a laboratory, typically in a batch flow mode. In many lab-scale studies, known concentration of CECs of interest are added to ("spiked" into) the test system.

Water/Waste Type – Identifies studied medium, for example, water, wastewater, groundwater, and manure waste.

Spiked Data – Results from studies in which a known amount of CEC was added to the test system. In these studies, researchers know the exact quantity of CEC entering a treatment operation, so they can accurately assess the operation's performance. In the database, most of the spiked data are from studies using distilled/clean water.

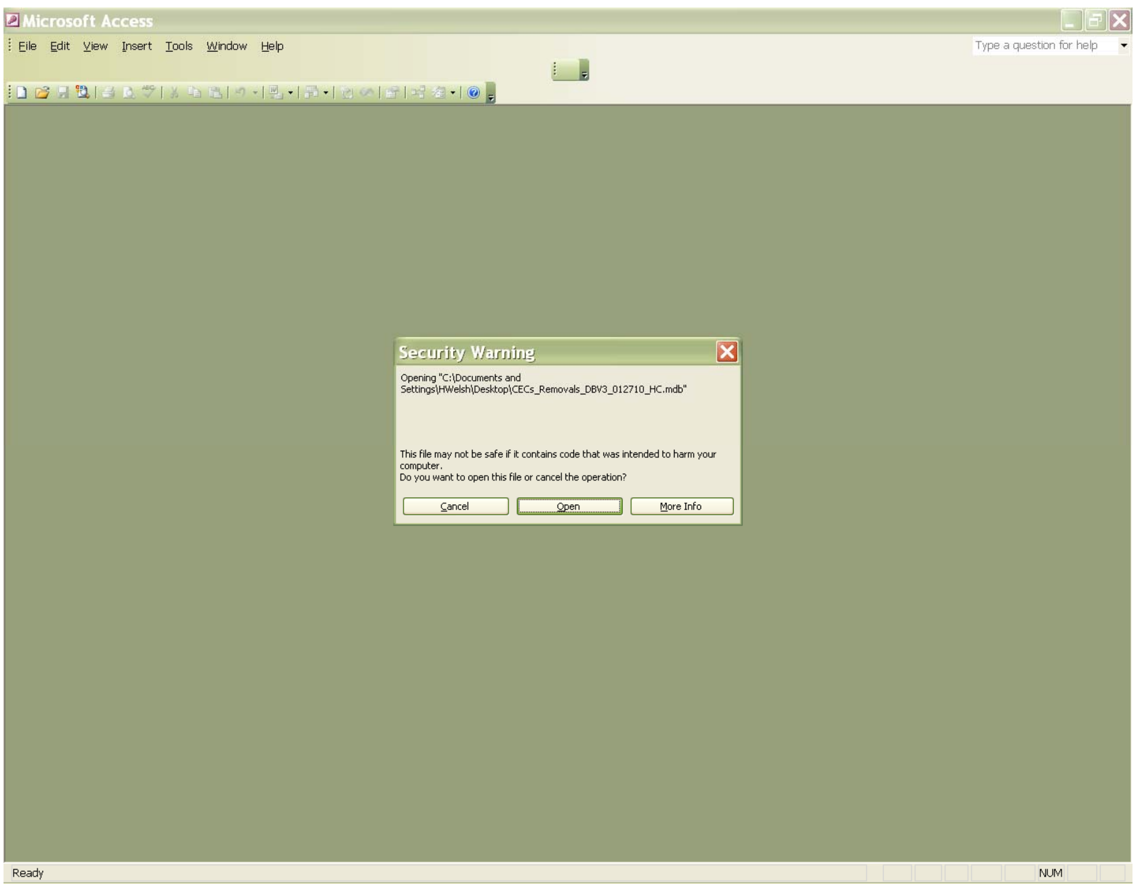
Using the Quick Search

You can use the Quick Search in the database to select the types of studies to include in the calculated average percent removals.

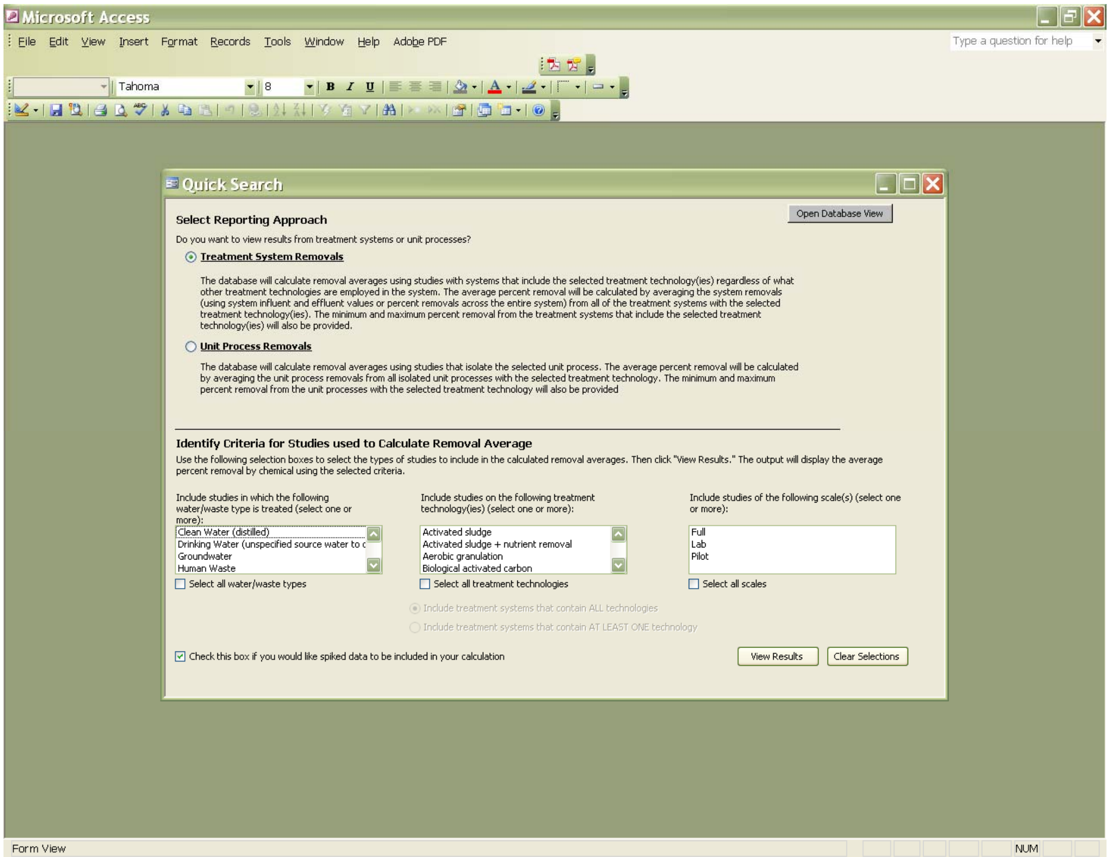
1. Save the *CEC Removals Database* to your desktop or another local computer drive.

2. Double click the database icon (or filename) to open the database.

3. When the "Security Warning" dialog box pops up, click "open."



4. The Quick Search will appear as the database opens. You will use the Quick Search to select the types of studies to include in the calculated average percent removals. You can pick from various treatment technology(ies), water/waste type(s), and scale(s).



5. First, determine which reporting approach you would like to use to calculate your average percent removals.
    a. <u>Treatment System Option</u> – If you select the treatment system option, the database will calculate average percent removals using all studies with treatment systems that include the selected treatment technology(ies) regardless of what other treatment technologies are employed in the system. The percent removal will be calculated by averaging the system removals (using system influent and effluent values or percent removals across the entire system) from all of the treatment systems with the selected treatment technology(ies). The minimum and maximum percent removal will be reported for each CEC as well.
    b. <u>Unit Process Option</u> – If you select the unit process option, the database will calculate average percent removals using studies that isolate the selected unit process (treatment technology). The percent removal will be calculated by averaging the removals from unit processes with the selected treatment technology. The minimum and maximum percent removal will be reported for each CEC as well.

    c. See page B-10 for some examples that show the distinction between selecting treatment system or unit process options.

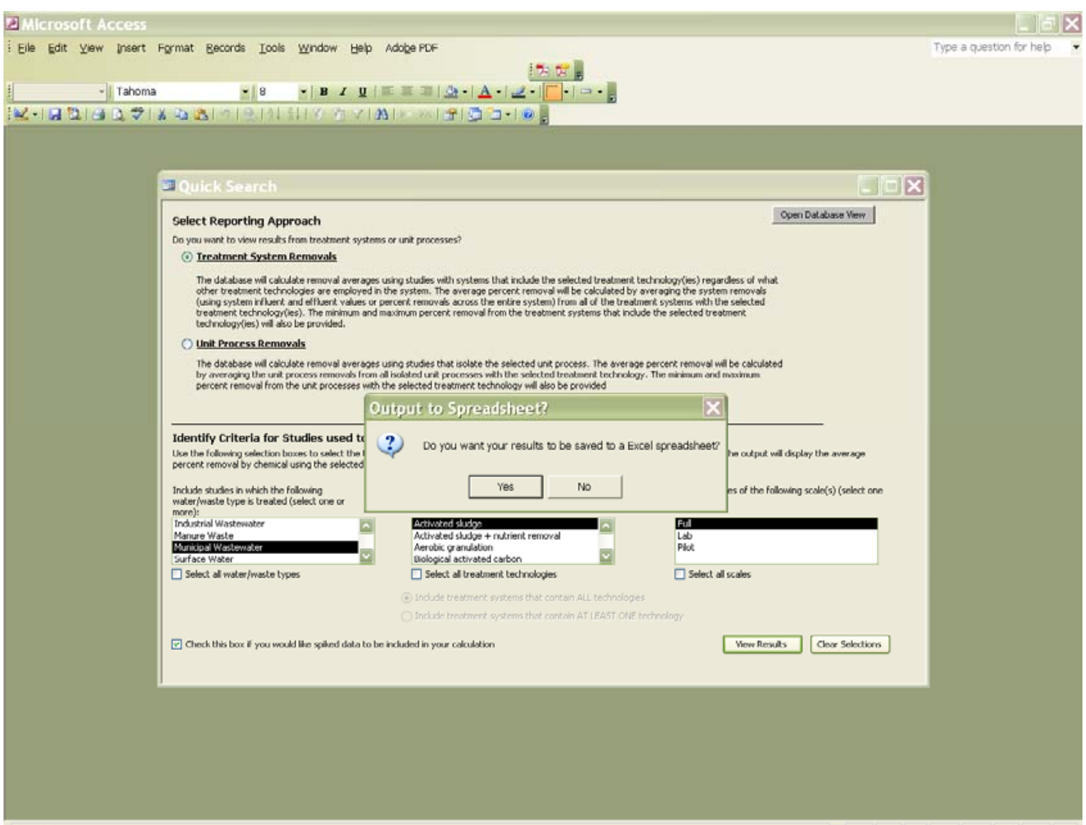
6. After you select a reporting approach, select the criteria for studies to include in the calculated average percent removals. Select one or more treatment technology(ies) (one or more than one if you selected the treatment system

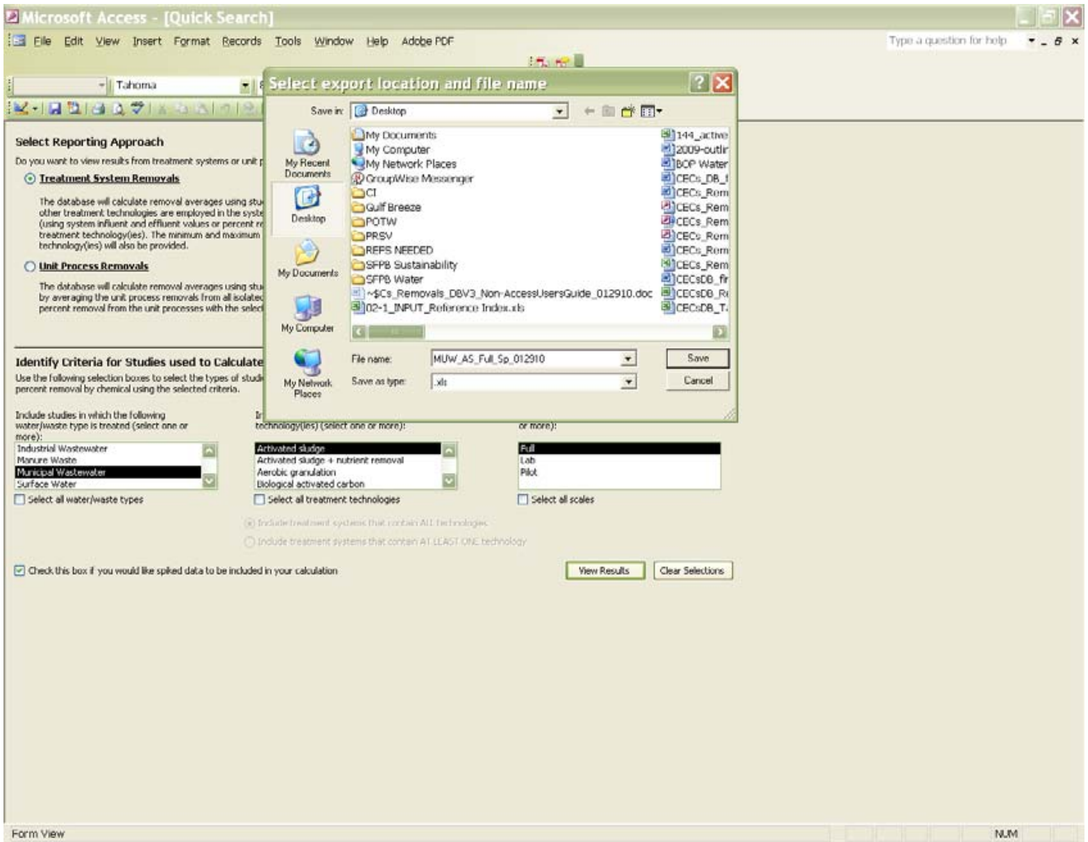
reporting approach and only one if you selected the unit process reporting approach), treatment scale(s), and water/waste type(s) (note that percent removal averages will not be calculated among water/waste types but can be reported for multiple water/waste types in one report). In addition, indicate if you would like spiked CEC data to be included. Only data from records that include the technology(ies), scale(s), and water/waste type(s) you selected will be included in the average percent removals. If you change your selections, make sure to un-highlight your earlier choices or click the “Clear Selections” button in the bottom, right corner of the Quick Search.

7. Finally, if you are using the treatment system option and you selected more than one treatment technology, indicate if you would like your average percent removals to contain records that have all of the treatment technologies you selected or at least one of the treatment technologies you selected. See Attachment 1 for some examples that show the distinction between selecting ALL or AT LEAST ONE.

8. After making your selections, click “View Results.”

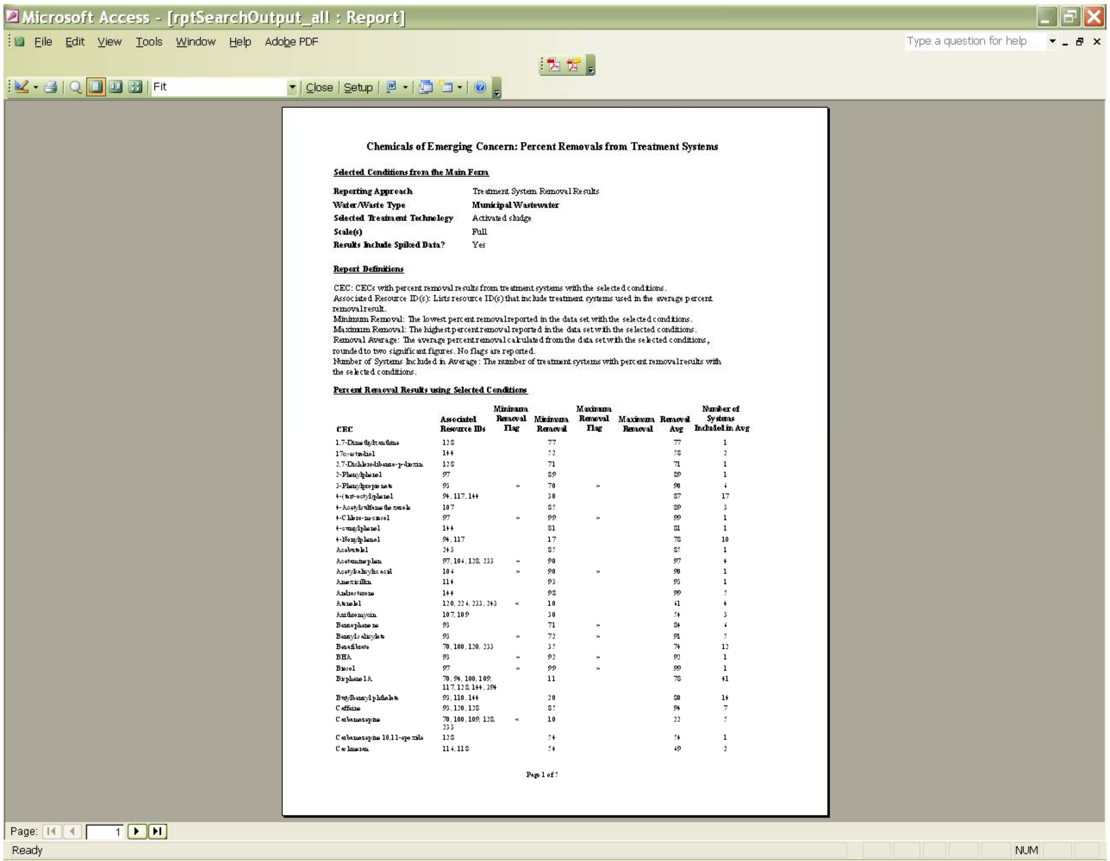
9. A dialog box will pop-up and ask you if you’d like to save your results to a Microsoft Excel® spreadsheet. Click “Yes” to save a spreadsheet with your results, choose the location where you would like to save the file, and provide a file name. Click “No” to only see the Access® report.





10. Whether you selected “Yes” or “No”, the Access® report will be generated, which shows average percent removals calculated from treatment systems or unit processes that meet your selection criteria. Your selections will be displayed at the top of the report and some key definitions for terminology used on the report will be provided. Below, average percent removal (presented without qualifier flags and rounded to two significant figures), maximum percent removal, and minimum percent removal will be reported for each CEC included in the studies that met your selected criteria. The minimum and maximum percent removals may be preceded by a “<” or “>” flag. Data were flagged if influent, effluent, or percent removal were flagged in the published study[4]. The identification numbers for the reference which contained data included in the average percent removal and the number of treatment systems or unit processes used to calculate the averages are also displayed.

[4] For example, if the influent is reported as 10 ng/l and the effluent is reported as <5 ng/l, the percent removal would be reported as >50%. Similarly, if the influent is reported as >10 ng/l and the effluent is reported as 5 ng/l, the percent removal would be reported as <50%. If the influent and effluent are both flagged, the percent removal cannot be identified as a minimum or maximum and is not flagged. In some cases, the study reported only flagged percent removal. In these cases, the reported flags are retained in the *CEC Removals Database*.



Chemicals of Emerging Concern: Percent Removals from Treatment Systems

Selected Conditions from the Main Form

Reporting Approach	Treatment System Removal Results
Water/Waste Type	**Municipal Wastewater**
Selected Treatment Technology	Activated sludge
Scale(s)	Full
Results Include Spiked Data?	Yes

Report Definitions

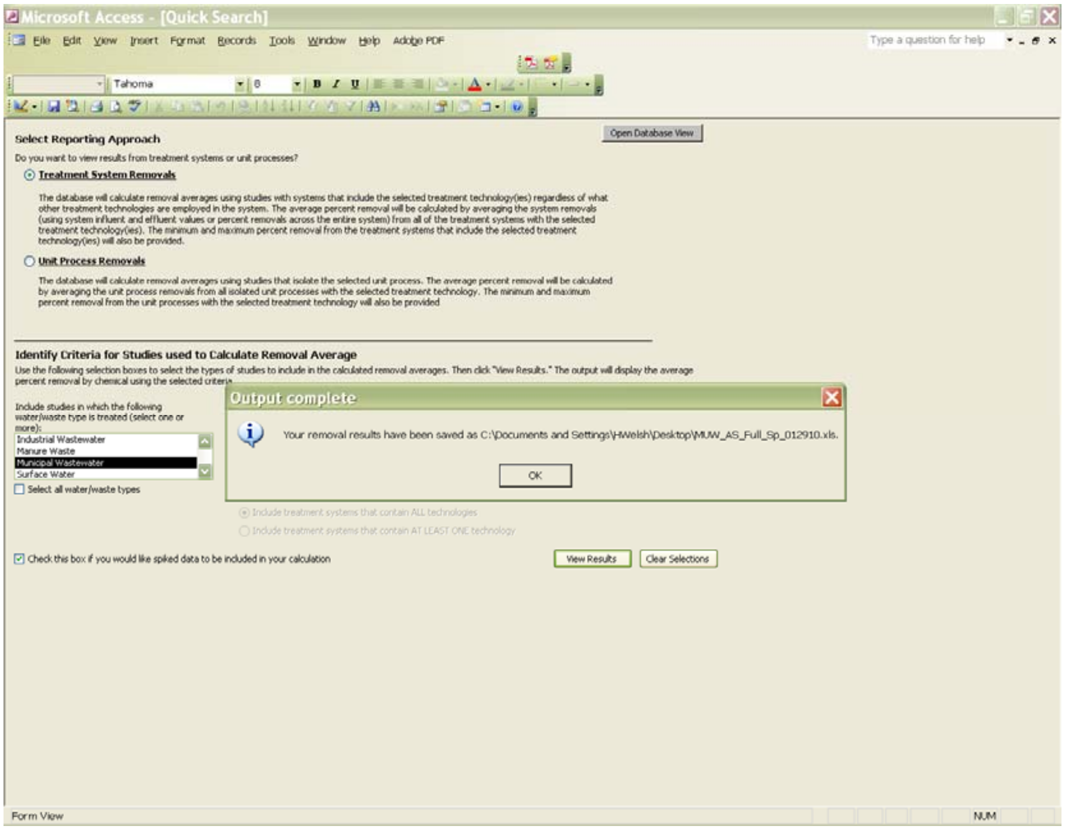
CEC: CECs with percent removal results from treatment systems with the selected conditions.
Associated Resource ID(s): Lists resource ID(s) that include treatment systems used in the average percent removal result.
Minimum Removal: The lowest percent removal reported in the data set with the selected conditions.
Maximum Removal: The highest percent removal reported in the data set with the selected conditions.
Removal Average: The average percent removal calculated from the data set with the selected conditions, rounded to two significant figures. No flags are reported.
Number of Systems Included in Average: The number of treatment systems with percent removal results with the selected conditions.

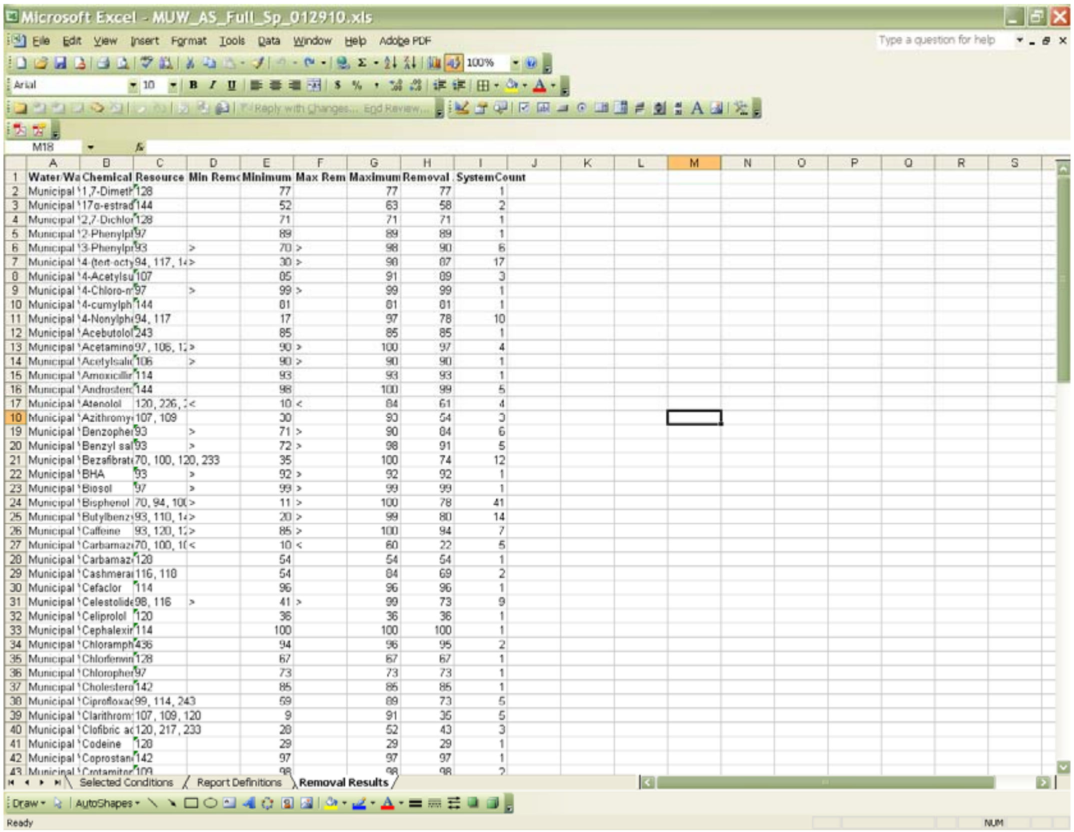
Percent Removal Results using Selected Conditions

CEC	Associated Resource IDs	Minimum Removal Flag	Minimum Removal	Maximum Removal Flag	Maximum Removal	Removal Avg	Number of Systems Included in Avg
1,7-Dimethylxanthine	128		77			77	1
17α-estradiol	144		52			58	2
2,7-Dichlorodibenzo-p-dioxin	128		71			71	1
2-Phenylphenol	97		89			89	1
3-Phenylpropionate	93	>	70	>		90	6
4-(tert-octyl)phenol	94, 117, 144		30			87	17
4-Acetylsulfamethoxazole	107		85			89	3
4-Chloro-m-cresol	97	>	99	>		99	1
4-cumylphenol	144		81			81	1
4-Nonylphenol	94, 117		17			78	10
Acebutolol	243		85			85	1
Acetaminophen	97, 106, 128, 233	>	90			97	4
Acetylsalicylic acid	106	>	90	>		90	1
Amoxicillin	114		93			93	1
Androsterone	144		98			99	5
Atenolol	120, 226, 233, 243	<	10			61	4
Azithromycin	107, 109		30			54	3
Benzophenone	93		71	>		84	6
Benzyl salicylate	93	>	72	>		91	5
Bezafibrate	70, 100, 120, 233		35			74	12
BHA	93	>	92	>		92	1
Biosol	97	>	99	>		99	1
Bisphenol A	70, 94, 100, 109, 117, 128, 144, 394		11			78	41
Butylbenzyl phthalate	93, 110, 144		20			80	14
Caffeine	93, 120, 128		85			94	7
Carbamazepine	70, 100, 109, 128, 233	<	10			22	5
Carbamazepine 10,11-epoxide	128		54			54	1
Cashmeran	116, 118		54			69	2

Page 1 of 5

11. If you selected “yes” that you would like an Excel® version of the Access® report, you can view the Excel® file in the folder that you specified.


Microsoft Access - [Quick Search]
Select Reporting Approach
Open Database View
Do you want to view results from treatment systems or unit processes?
Treatment System Removals
The database will calculate removal averages using studies with systems that include the selected treatment technology(ies) regardless of what other treatment technologies are employed in the system. The average percent removal will be calculated by averaging the system removals (using system influent and effluent values or percent removals across the entire system) from all of the treatment systems with the selected treatment technology(ies). The minimum and maximum percent removal from the treatment systems that include the selected treatment technology(ies) will also be provided.
Unit Process Removals
The database will calculate removal averages using studies that isolate the selected unit process. The average percent removal will be calculated by averaging the unit process removals from all isolated unit processes with the selected treatment technology. The minimum and maximum percent removal from the unit processes with the selected treatment technology will also be provided
Identify Criteria for Studies used to Calculate Removal Average
Use the following selection boxes to select the types of studies to include in the calculated removal averages. Then click "View Results." The output will display the average percent removal by chemical using the selected criteria.
Include studies in which the following water/waste type is treated (select one or more):
Industrial Wastewater
Manure Waste
Municipal Wastewater
Surface Water
Select all water/waste types
Output complete
Your removal results have been saved as C:\Documents and Settings\HWelsh\Desktop\MUW_AS_Full_Sp_012910.xls.
OK
Include treatment systems that contain ALL technologies
Include treatment systems that contain AT LEAST ONE technology
Check this box if you would like spiked data to be included in your calculation
View Results
Clear Selections
Form View


Microsoft Excel - MUW_AS_Full_Sp_012910.xls
Water/Wa Chemical Resource Min Remo Minimum Max Rem Maximum Removal SystemCount
Selected Conditions
Report Definitions
Removal Results
Ready

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
114	Watkinson, A. J.; E. J. Murby; and S. D. Costanzo	2007	Removal of antibiotics in conventional and advanced treatment: Implications for environmental discharge and wastewater recycling	Water Research (journal) and Elsevier (publisher)	41; 4164-4176	Other	full	The removal of 28 human and veterinary antibiotics was assessed in a Brisbane, Australia WWTP which uses conventional (activated sludge) and advanced (microfiltration/reverse osmosis) treatments. Different points in the treatment train constitute the different "treatment systems" reported in the database. Conventional treatment removed, on average, 89% of all antibiotics. The MF/RO plant received its influent from the effluent of the conventional treatment plant and removed 94% of all incoming antibiotics (from the 11% not removed upstream).
115	Winkler, G.; R. Fischer, P. Krebs; A. Thompson; E. Cartmell; and P. Griffin	2007	Mass flow balances of triclosan in rural wastewater treatment plants and the impact of biomass parameters on the removal	Engineering in Life Sciences (journal) Wiley (publisher)	7; 42-51	Europe	full	Three United Kingdom wastewater treatment plants - rotating biological contactor (RBC), trickling filter (TF), and oxidation ditch (OD) - were analyzed for triclosan at different treatment stages. Overall average percent removals were 81, 96 and 92 for RBC, OD and TF, respectively. The authors discovered that several biomass parameters (fat content, pH and temperature) have an effect on triclosan removal rates.
116	Yang, J. J.; C. Metcalfe	2006	Fate of synthetic musks in a domestic wastewater treatment plant and in an agricultural field amended with biosolids	Science of the Total Environment (journal) and Elsevier (publisher)	363; 149-165	Canada	full	Eleven synthetic musks were analyzed at various stages of a WWTP using activated sludge in Ontario (Peterborough WWTP). The overall removal percentages ranged from 43.3% to 56.9%. A final UV-disinfection step did not decrease the concentrations of synthetic musks in the WWTP effluent.
117	Ying, Guang-Gou; Rai Kookana; Anu Kumar	2008	Fate of estrogens and xenoestrogens in four sewage treatment plants with different technologies	Environmental Toxicology and Chemistry (journal) and SETAC Press (publisher)	27; 87-94	Other	full	Four WWTP's in South Australia were evaluated in their abilities to remove four estrogens and five xenoestrogens. Effluent concentrations and removal efficiencies are given for all four plants. On average, conventional activated sludge and oxidation ditch treatments removed estrogenic compounds better than lagoons and bioreactors.
118	Zeng, Xiangying; Guoying Sheng; Hongyan Gui; Duohong Chen; Wenlan Shao; Jiamo Fu	2007	Preliminary study on the occurrence and distribution of polycyclic musks in a wastewater treatment plant in Guandong, China	Chemosphere (journal) and Elsevier (publisher)	69:1305-1311	Other	full	The influent, primary effluent and final effluent stages of a WWTP in China were analyzed for six polycyclic musks. Samples were collected from each stage at four hour intervals for a 24-hour period. Of the three musks detected, the removal efficiencies were: 1) DPMI: 61-79%; 2) HHCB: 86-97%; and 3) AHTN: 87-96%. The authors suggest that transfer to sludge is the main removal route.
120	Ternes, Thomas A.; Matthias Bonerz; Nadine Herrmann; Bernhard Teiser; Henrik Rasmus Andersen	2006	Irrigation of treated wastewater in Braunschweig, Germany: An option to remove pharmaceuticals and musk fragrances.	Chemosphere (journal) and Elsevier (publisher)	66: 894-904	Europe	full	A case study was performed Braunschweig, Germany to investigate the use of secondary treated sewage as irrigation of agricultural land. The paper discusses the suitability of soil aquifer treatment as a tool within the indirect reuse scheme of municipal wastewater to remove PPCPs. During soil-aquifer passage most of the PPCPs (80%) are degraded and a few are sorbed.
124	Bundy, Michael M.; William J. Doucette; Laurie McNeill; Jon F. Ericson	2007	Removal of pharmaceuticals and related compounds by a bench-scale drinking water treatment system	Journal of Water Supply: Research and Technology (journal) and IWA Publishing (publisher)	56: 105-115	U.S.	lab	A bench-scale drinking water treatment system was set up to study the effectiveness of four unit operations: coagulation/sedimentation/flocculation, dual-media gravity filtration, granular activated carbon and chlorination disinfection. Four pharmaceutical analytes – caffeine, trovafloxacin mesylate, estradiol and salicyclic acid – were analyzed after each treatment and for the influent, Logan River water spiked with analytes. Granular activated carbon accounted for the largest percent removal for caffeine, trovafloxacin and estradiol but had limited impact on salicyclic acid.

Table C-1. Literature Review Bibliography (Continued)

ID	Authors	Date	Title	Journal/Publisher	Volume/Pages	Geographic Scope	Scale	Abstract
125	Carballa, Marta; Fransesco Omil; Juan M. Lema	2007	Calculation methods to perform mass balances of micropollutants in sewage treatment plants. Application to pharmaceutical personal care products (PPCPs)	Environmental Science and Technology (journal) and American Chemical Society (publisher)	41:884-890	Europe	full	Two methods (calculated data and measured data) are used to perform mass balance calculations to determine the mechanism of removal of 3 pharmaceuticals, 2 musks and 2 natural estrogens. According to mass balances using measured data, the removal efficiencies of the pharmaceuticals ranged from 65 to 90 percent, while the musks' removal efficiencies were roughly 50 percent. While the pharmaceuticals were largely degraded chemically, the musks were degraded and absorbed onto the sludge equally. Estrogens were not removed by the STP.
126	Esperanza, Mar; Makram T. Suidan; Fumitake Nishimura; Zhong-Min Wang; George A. Sorial	2004	Determination of Sex Hormones and Nonylphenol Ethoxylates in the Aqueous Matrixes of Two Pilot-scale Municipal Wastewater Treatment Plants	Environmental Science and Technology (journal) and American Chemical Society (publisher)	38:3028-3035	U.S.	pilot	Seven sex hormones and a group of nonionic surfactants and their biodegradation byproducts were measuring using two analytical methods developed for quantitation. The analytes were spiked in two pilot plants (one with anaerobic digestion and one with aerobic digestion). Testosterone, androsenedione, and progesterone were completely removed from the aqeous phase. Removal for nonylphenol pollyethoxylates, estradiol, estrone, and ethinylestradiol from the aqeous phase exceed 96%, 94%, 52%, and 50%, respectively.
128	Gomez, M.J., M.J. Martinez Bueno, S. Lacorte, A.R. Fernandez-Alba, A. Aguera	2007	Pilot Survey Monitoring Pharmaceuticals and Related Compounds in a Sewage Treatment Plant Located on the Mediterranean Coast	Chemosphere (journal) and Elsevier (publisher)	66:993-1002	Europe	full	The article summarizes a one-year monitoring study performed at a sewage treatment plant in Spain. The study was performed to evaluate the occurrence, persistence, and fate of 14 organic compounds (pharmaceuticals, plasticizers, antiseptics, insecticides, and stimulants) in waste water influent and treatment plant effluent. The removal efficiencies of the STP for these compounds varied from 20% (carbamazepine) to 99% (acetaminophen), but in all cases resulted insufficient in order to avoid their presence in treated water and subsequently in the environment.
130	Hu, J.Y., X. Chen, G. Tao, K. Kekred	2007	Fate of Endocrine Disrupting Compounds in Membrane Bioreactor Systems	Environmental Science & Technology (journal) and American Chemical Society (publisher)	41:4097-4102	Other	lab, pilot	This study investigates the fate of endocrine disrupting compounds in waste water in three pilot-scale and two lab-scale membrane bioreactor systems in Singapore. Influent and effluent water data were collected for each system. Influents to the test systems were from a local water reclamation plant. E1 and E2 were removed with at least moderate efficiency. E1-3S, E1-3G, and E2-G were not well removed. BPA was well removed but 4-nonylphenol was amplified.
133	Jasmin, Saad Y.; Antonette Irabelli; Paul Yang; Shamima Ahmed; L. Schweitzer	2006	Presence of Pharmaceuticals and Pesticides in Detroit River Water and the Effect of Ozone on Removal	Ozone: Science and Engineering (journal) and International Ozone Association (publisher)	28:415-423	Canada	full, pilot	This study was completed to evaluate the efficacy of conventional drinking water treatment (coagulation, flocculation, sedimentation, and sand filtration) with and without ozone at reducing concentrations of PPCP and pesticides.Two pilot plants and a full scale conventional drinking water treatment plant were sampled for raw water and effluent contaminant conentrations. The analysis indicated that trace levels of compounds such as carbamazepine, caffeine, cotinine, and atrazine were detectedin raw water and that treatment with ozone resulted in a greater removal versus conventional treatment.

Table C-1. Literature Review Bibliography (Continued)

ID	Authors	Date	Title	Journal/Publisher	Volume/Pages	Geographic Scope	Scale	Abstract
140	Snyder, Shane; Eric Wert; David Rexing; Ronald Zegers; Douglas Drury	2006	Ozone oxidation of endocrine disruptors and pharmaceuticals in surface water and wastewater	Ozone: Science and Engineering (journal) and Taylor & Francis (publisher)	28:445-460	U.S.	full, pilot	Bench and pilot scale ozonation (with hydrogen peroxide) experiments were conducted with surface water spiked with the target compounds and wastewater effluent containing ambient concentrations of target compounds. Full-scale treatment plants were sampled before and after ozonation to determine if bench- and pilot-scale results accurately predict full-scale removal. In both drinking and wastewater experiments, most compounds were removed by greater than 90%.
141	Sponza, Delia Teresa; Hulya Atalay	2006	Simultaneous toxicity and nutrient removals in simulated DEPHANIX (anaerobic/anoxic/oxic sequentials) process treating antibiotics	Fresenius Environmental Bulletin (journal) and PSP (publisher)	15:753-762	Europe	lab	The purpose of this study was to evaluate the effect of methanogenic and anoxic conditions on the fate of kemicetine (chloramphenicol), together with nutrient removal. A modified DEPHANOX process, consisting of two upflow sludge blanket reactors, an anaerobic-upflow sludge blanket and an anoxic-upflow sludge blanket, and an aerobic completely stirred tank reactor, was analyzed for simultaneous removal of kemicetine and nutrients. The only reportable data from this paper were removal efficiencies of kemicetine from the anaerobic and aerobic reactors at variable kemicetine loading rates which were typically 90% or greater.
142	Spring, A. J.; D. M. Bagley; R. C. Andrews; S. Lemanik; P. Yang	2007	Removal of endocrine disrupting compounds using a membrane bioreactor and disinfection	Journal of Environmental Engineering and Science (journal) and NRC Canada (publisher)	6:131-137	Canada	full, pilot	A membrane bioreactor removed greater than 96% of suspected endocrine disrupting compounds cholesterol, coprostanol and stigmastanol compared to 85% removal for a conventional treatment plant receiving the same influent. It is unknown whether this improvement over conventional treatment is due to the membrane or the increased sludge retention time.
144	Tan, Benjamin L.L.; Darryl W. Hawker; Jochen F. Muller; Frederic D.L. Leusch; Louis A. Tremblay; Heather F. Chapman	2007	Comprehensive study of endocrine disrupting compounds using grab and passive sampling at selected wastewater treatment plants in South East Queensland, Australia	Environment International (journal) and Elsevier (publisher)	33:654-669	Other	full	This study was completed to compare various sampling and analysis methods for endocrine disrupting compounds, including grab and passive sampling, gas chromatography-mass spectrometry, and biological assay analysis. Data were collected from several wastewater treatment plants for EDCs including influent, effluent, and intermediate wastewater samples. The results of the study indicated that the removal efficacy of conventional activated sludge or biological nutrient removal WWTPs for most estrogenic compounds ranged from 80 to >99%. Passive sampling was concluded to be a useful too which still requires additional research into how to interpret passive sampling results.
146	Ternes, Thomas; Jeanette Stuber; Nadine Herrman; Derek McDowell; Achim Ried; Martin Kampmann; Bernhard Teiser	2003	Ozonation: a tool for removal of pharmaceuticals, contrast media and musk fragrances from wastewater?	Water Research (journal) and Elsevier (publisher)	37:1976-1982	Europe	pilot	A pilot plant for ozonation and UV-disinfection received effluent from a German municipal sewage treatment plant (STP) to test the removal of pharmaceuticals, iodinated X-ray contrast media (ICM) and musk fragrances from municipal wastewater. By applying 10–15 mg ozone, all the pharmaceuticals investigated as well as musk fragrances (HHCB, AHTN) and estrone were no longer detected. However, ICM (diatrizoate, iopamidol, iopromide and iomeprol) were still detected in appreciable concentrations. Advanced oxidation processes which were non-optimized for wastewater treatment, did not lead significantly to a higher removal efficiency for the ICM than ozone alone.

Table C-1. Literature Review Bibliography (Continued)

ID	Authors	Date	Title	Journal/Publisher	Volume/Pages	Geographic Scope	Scale	Abstract
148	Vieno, Niina M.; Heli Harkki; Tuula Tuhkanen; Leif Kronberg	2007	Occurrence of Pharmaceuticeuticals in River Water and Their Elimination in a Pilot-Scale Drinking Water Treatment Plant	Environmental Science & Technology (journal) and American Chemical Society (publisher)	41:5077-5084	Europe	pilot	This study was completed to test for the presence of pharmaceuticals in the River Vantaa, and quatify their removal in a pilot-scale drinking water plant using this water source. The drinking water plant featured coagulation and sedimentation, sand filtration, UV disinfection, and granular activated carbon filtration with and without ozonation. The treatment train was found to very effectively eliminate the pharmaceuticals from the raw water. The only compound that was found to pass almost unaffected through all the treatment steps was ciprofloxacin.
150	Zhou, Ping; Chengyi Su; Binwei Li; Yi Qian	2006	Treatment of High-Strength Pharmaceutical Wastewater and Removal of Antibiotics in Anaerobic and Aerobic Biological Treatment Processes	Journal of Environmental Engineering (journal) and ASCE (publisher)	132:129-136	Other	lab, pilot	This study evaluates anaerobic and aerobic treatment of high-strength pharmaceutical wastewater. A batch test was performed to study the biodegradability of the waste water followed by a pilot-scale test composed of an anaerobic baffled reactor and a biofilm airlift suspension reactor. Removal efficiencies were not higher than 50% in either pilot-scale system.
196	Batt, AL; Sungpyo Kim; DS Aga	2006	Enhanced Biodegradation of Iopromide and Trimethoprim in Nitrifying Activated Sludge	Environmental Science and Technology (journal) and American Chemical Society (publisher)	40:7367-7373	U.S.	full, lab	The article investigates the nitrification of activated sludge as a removal mechanism for iopromide and trimethoprim. The lab scale tests were corroborated by the observed removal efficiencies in a full scale municipal WWTP, which showed that iopromidie and trimethoprim were removed more effectively in the nitrifying activated sludge which has a higher SRT than in the conventional activated sludge.
197	Bila, Daniele; Antonio F. Montalva; Debora de A. Azevedo; Marcia Dezotti	2007	Estrogenic activity removal of 17b estradiol by ozonation and identification of by-products	Chemosphere (journal) and Elsevier (publisher)	69: 736-746	Other	lab	This work investigated the degradation of a natural estrogen (17b-estradiol) and the removal of estrogenic activity by the ozonation process in three different pHs (3, 7 and 11). High removals (>99%) were achieved with low ozone dosages in the three different pHs. A recombinant yeast (YES) assay determined that the byproducts of ozonation at higher pHs have a higher estrogenicity that those at lower pHs.
201	Chelliapan, Shreeshivadasan; Thomas Wilby, Paul J. Sallis	2006	Performance of an up-flow anaerobic stage reactor (UASR) in the treatment of pharmaceutical wastewater containing macrolide antibiotics	Water Research (journal) and Elsevier (publisher)	40:507-516	Europe	lab	The performance of an up-flow anaerobic stage reactor (UASR) treating pharmaceutical wastewater containing macrolide antibiotics was investigated. The reactor was fed with real pharmaceutical wastewater containing Tylosin and Avilamycin antibiotics and operated with step-wise increases in the reactor organic loading rate (OLR). An average of 95% Tylosin reduction was achieved in the UASR, indicating that this antibiotic could be degraded efficiently in the anaerobic reactor system. Additionally, high removals of Tylosin were achieved regardless of high fluctuations in the Tylosin influent load. This study concludes that a UASR can be used effectively as an option for pre-treatment of pharmaceutical wastewaters that contain Tylosin and Avilamycin macrolide antibiotics.
210	Ifeleguegu, A.O.; J.N. Lester; J. Churchley; E. Cartmell	2006	Removal of an endocrine disrupting chemical (17 alpha-ethinyloestradiol) from wastewater effluent by activated carbon adsorption: Effects of activated carbon type and competitive adsorption	Environmental Technology (journal) and Selper Ltd. (publisher)	27:1343-1349	Europe	lab	GAC is considered to be an effective treatment for the removal of synthetic organic chemicals in potable water treatment. However, it's use in wastewater treatment has not been adequately evaluated. The removal of EE2, TOC, UV and COD by different types of activated carbon were investigated in this study. The results demonstrate thathe EE2, COD, TOC and UV adsorbance were effectively removed by all three methods of activated carbon.

Table C-1. Literature Review Bibliography (Continued)

ID	Authors	Date	Title	Journal/Publisher	Volume/Pages	Geographic Scope	Scale	Abstract
214	Joss, A.; H. Andersen; T. Ternes; P.R. Richle; H. Siegrist	2004	Removal of estrogens in municipal wastewater treatment under aerobic and anaerobic conditions: Consequences for plant optimization	Environmental Science & Technology (journal) and American Chemical Society (publisher)	38:3047-3055	Europe	full, pilot	In this paper, the removal of estrone (E1), estradiol (E2), and ethinylestradiol (EE2) in sludge from a municipal WWTP with nitrogen removal (nitrification/denitrification) is investigated in spiked batch experiments. Full-scale activated sludge, MBR and fixed bed reactor treatment is sampled and compared to the proposed model. A biological degradation model is proposed and discussed with sampling campaigns on full-scale WWTPs. The compounds were found to be removed mainly in activated sludge compartments with low substrate loading. The results show a removal of >90% for all estrogens in the activated sludge process.
215	Kim, Sungpyo; Peter Eichhorn; James N. Jensen; A. Scott Weber; Diana S. Aga	2005	Removal of Antibiotics in Wastewater: Effect of Hydraulic and Solid Retention Times on the Fate of Tetracycline in the Activated Sludge Process	Environmental Science & Technology (journal) and American Chemical Society (publisher)	39:5816-5823	U.S.	lab	The article describes a study conducted to examine the influence of hydraulic retention time (HRT) and solid retention time (SRT) on the removal of tetracycline in the activated sludge processes. Two lab-scale sequencing batch reactors (SBRs) were operated to simulate the activated sludge process. One SBR was spiked with 250 ug/L tetracycline, while the other SBR was evaluated at tetracycline concentrations found in the influent of the wastewater treatment plant (WWTP) where the activated sludge was obtained. The concentrations of tetracyclines in the influent of the WWTP ranged from 0.1 to 0.6 ug/L. Three different operating conditions were applied during the study (phase 1 HRT: 24 h and SRT: 10 days; phase 2 HRT: 7.4 h and SRT: 10 days; and phase 3 HRT: 7.4 h and SRT: 3 days). The removal efficiency of tetracycline in phase 3 (78.4 (7.1%) was significantly lower than that observed in phase 1 (86.4 (8.7%) and phase 2 (85.1 (5.4%) at the 95% confidence level. The reduction of SRT in phase 3 while maintaining a constant HRT decreased tetracycline removal efficiency.
217	Kimura, Katsuki; Hiroe Hara; Yoshimasa Watanabe	2007	Elimination of selected acidic pharmaceuticals from municipal wastewater by an activated sludge system and membrane bioreactors	Environmental Science & Technology (journal) and American Chemical Society (publisher)	41:3708-3714	Other	full, pilot	The elimination of six pharmaceuticals was investigated in an activated sludge WWTP and two membrane bioreactors. Different elimination mechanisms were tested in all three treatment systems. The main mechanism of elimination of the pharmaceuticals in the investigated processes was found to be biodegradation.
218	Kosjek, Tina; Ester Heath; Boris Kompare	2007	Removal of pharmaceutical residues in a pilot wastewater treatment plant	Analytical and Bioanalytical Chemistry (journal) and Springer (publisher)	387:1379-1387	Europe	lab	The study focuses on removal of commonly used NSAIDs (ibuprofen, naproxen, ketoprofen, diclofenac) and clofibric acid in a specially designed small-scale activated sludge pilot wastewater treatment plant (PWWTP). This study shows that, except for diclofenac, steady-rate removal of NSAIDs over a two-year monitoring period has been achieved. Elimination of the compounds in the PWWTP was ≥87% for ibuprofen, naproxen and ketoprofen but only 49–59% for diclofenac. Clofibric acid was also examined with the results after one month of operation of 30% elimination with no sign of adaptation by the biomass.

Table C-1. Literature Review Bibliography (Continued)

ID	Authors	Date	Title	Journal/Publisher	Volume/Pages	Geographic Scope	Scale	Abstract
223	Matamoros, Victor; Joan Garcia; Joseph M. Bayona	2005	Behavior of Selected Pharmaceuticals in Subsurface Flow Constructed Wetlands: A Pilot-Scale Study	Environment Science & Technology (journal) and American Chemical Society (publisher)	39:5449-5454	Europe	pilot	This study evaluated the effectiveness of a pilot scale subsuface flow constructed wetland receiving residential wastewater at removing several pharmaceuticals which were continuously spiked into the system influent. Less refractory compounds such as ibuprofen are removed more efficiently in the shallow SSF, presumably linked to more oxidized conditions. The more refractory pharmaceuticals such as clofibric acid show no removal, in agreement to limited removal observed in WWTPs. Carbamazepine removal was higher in the deep bed, but poor (~20% on average) in both SSFs.
224	Matamoros, Victor; Josep M. Bayona	2006	Elimination of Pharmaceuticals and Personal Care Products in Subsurface Flow Constructed Wetlands	Environment Science & Technology (journal) and American Chemical Society (publisher)	40:5811-5816	Europe	pilot	This study examined the elimination of pharmaceuticals and personal care products in two horizontal subsurface flow constructed wetlands which received urban residential wastewater from a 200 person housing development. PPCPs were classified by their removal behavoir: (1) those efficiently removed, namely caffine, salicylic acid, and methyl dihydrojasmonate (>80%); (2) those moderately removed, namely ibuprofen, hydroxy-ibuprofen, and naproxen (50-80%); (3) those recalcitrant to removal, namely ketoprofen and diclofenac; (4) and those which were removed mainly through sorption with the gravel bed, namely polycylic musks (i.e. galaxolide and tonalide).
225	Matamoros, Victor; Carlos Arias; Hans Brix; Josep M. Bayona	2007	Removal of Pharmaceuticals and Personal Care Products (PPCPs) from Urban Wastewater in a Pilot Vertical Flow Constructed Wetland and a Sand Filter	Environmental Science & Technology (journal) and American Chemical Society (publisher)	41:8171-8177	Europe	pilot	This study examined the removal efficiencies and elimination kinetics of 13 pharmaceuticals and personal care products in a pilot subsurface flow constructed wetland compared with a sand filter. The studies PPCPs were grouped by their removal efficiencies into (i) PPCPs which were easily removed, with >95% removal in one of the systems (caffeine, salicyclic acid, methyl dihydrojasmonate, carboxy-ibuprofen, hydroxy-ibuprofen, hydrocinnamic acid, oxybenzone, and ibuprofen) (ii) those PPCPs which were moderately removed (70 to 90% in the two systems) (naproxen, diclofenac, galaxolide, and tonalide) and finally (iii) those PPCPs which were poorly removed, i.e. less than 30% removal (carbamazepine).
226	Maurer, M., B.I. Escher; P. Richle; C. Schaffner; A.C. Alder	2007	Elimination of Beta-blockers in sewage treatment plants	Water Research (journal) and ELSEVIER (publisher)	41:1614-1622	Europe	full	This study investigated the elimination of beta-blockers in sewage treatment, by determining sorption rates and first-order elimination rates. These values were used to predict elimination in actual sewage treatment plants. Sampling was performed at two plants to confirm predicted removal efficiencies. Measured removal efficiencies ranged from 26 to 79 % for four beta-blockers.
233	Radjenovic, Jelena; Mira Petrovic; Damia Barcelo	2006	Analysis of pharmaceuticals in wastewater and removal using a membrane bioreactor	Analytical and Bioanalytical Chemistry (journal) and Springer (publisher)	387:1365-1377	Europe	full, lab	The behavior of several pharmaceutical products in different therapeutic categories was monitored during treatment of wastewater in a lab scale membrane bioreactor. The results were compared to conventional activated sludge. The MBR system, in general, had greater removals than the CAS system.

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.