Contaminants of Emerging Concern Report

Prepared by the Prairie Research Institute

The University of Illinois’ (U of I) Prairie Research Institute (PRI) provides objective scientific expertise, data, and applied research to aid decision making and provide solutions for government, industry, and the people of Illinois. PRI is the home of the state’s five scientific surveys: the Illinois Natural History Survey (INHS), Illinois State Archaeological Survey (ISAS), Illinois State Geological Survey (ISGS), Illinois State Water Survey (ISWS), and Illinois Sustainable Technology Center (ISTC).

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Document Intent

This report was created at the request of the Illinois Legislature in IL HB5741, passed in May 2018. It is a review of the state of scientific knowledge known about contaminants of emerging concern (CEC) in wastewater treatment plants (WWTPs). Concentrations of CEC in WWTPs and treatment technologies in the U.S. and other countries are discussed as well as U.S. federal and state laws. This document serves as factual evidence of CEC in WWTPs and should not be construed as advocating for a specific view on this issue.

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Abbreviations

CEC – contaminants of emerging concern

PFAS – per- and polyfluoroalkyl substances

PFOA – perfluorooctanoic acid

PFOS – perfluorooctanesulfonic acid

PPCP – pharmaceuticals and personal care products

µg/L – micrograms per liter

WWTPs – wastewater treatment plants

Executive Summary

## Introduction

* Definitions of terms used in this report:
  + Emerging Contaminants - new compounds or molecules that were not previously known or that just recently appeared in the scientific literature
  + Contaminants of Emerging Concern (CEC) - compounds that were known to exist but for which the environmental contamination issues were not fully realized or apprehended
* New information is constantly changing our understanding of environmental and human health risks related to the contaminants addressed in this report.
* Wastewater treatment plants (WWTPs) were not designed to remove CEC.
* Many sources add to CEC contamination besides WWTPs.
* Research on the impact of CEC on human and environmental health is just beginning.

## CEC Concentrations in WWTPs

* Concentrations in WWTPs are highly variable depending on population, location, time of year, and type of CEC.
* CEC in WWTPs have residential, commercial, and agricultural origins.

## Treatment Technologies

* No one treatment technology will destroy all CEC.
* Nearly all effective treatment technologies are only at the laboratory/experimental development stage (10-30 years from commercial market stage).
* Funding is needed for further research that develops and matures cost-effective technologies for treating these contaminants.
* WWTPs were not designed to remove CEC. Importantly, note that WWTPs were originally designed to reduce excess nutrients and pathogens before wastewater is released to local waterbodies.

## Legislative Actions

* No enacted legislation exists for CEC in WWTPs.
* The most any state has done is set up a task force or called for a review of these chemicals.
* Several states have proposed legislation for a task force or review, but most have not succeeded.
* Multiple states do have enacted legislation for CEC in public drinking water supplies or in firefighting foams.
* No state has set a maximum contaminant level for CEC in WWTPs.
* Several companies responsible for discharging these contaminants are being sued for the continued release of CEC.

# Introduction

## Definition of Contaminants of Emerging Concern

Contaminant buzzwords in the media and science journals such as lead, PFAS, and microplastics are on the rise. Articles use emerging issues, emerging contaminants, and contaminants of emerging concern (CEC) interchangeably, but they do not mean quite the same thing. Sauvé and Desrosiers’ 1 review paper describes the subtle differences between them:

* Emerging Contaminants - new compounds or molecules that were not previously known or that just recently appeared in the scientific literature
* Contaminants of Emerging Concern - compounds that were known to exist, but the environmental contamination issues are not fully realized or apprehended
* Emerging Issues - new information that changes our understanding of environmental and human health risks related to legacy contaminants

When conducting the literature search for this report, we included both emerging contaminants and contaminants of emerging concern (CEC) categories, but not the emerging issues category. We found that most of the information available fell under the CEC category. For simplicity, we refer to contaminants found in both the emerging contaminants and CEC categories as CEC.

## Sources, Endpoints, and Treatments

The request for this review document focused on CEC in wastewater treatment plants (WWTPs). However, other sources of CEC include:

* Industrial wastewater discharge
* NPDES permitted release waters
* Animal feeding operations
* Agricultural lands
* Landfills
* Humans

CEC are found in many environments:

* Surface water (lakes, rivers, oceans)2–12
* Groundwater (including karst groundwater)2–4
* Drinking water (tap and bottled)2,13
* Biosolids/sludge12,14–26
* Sediment27,28
* Plants29,30
* Animals31,32
* Humans33

Traditional wastewater treatment processes were designed to remove nutrients, solids, and pathogens from wastewater (Figure 1). They were not designed to remove CEC. Although the treatment processes do remove some CEC, many contaminants pass through the system unmodified and are released into the environment.

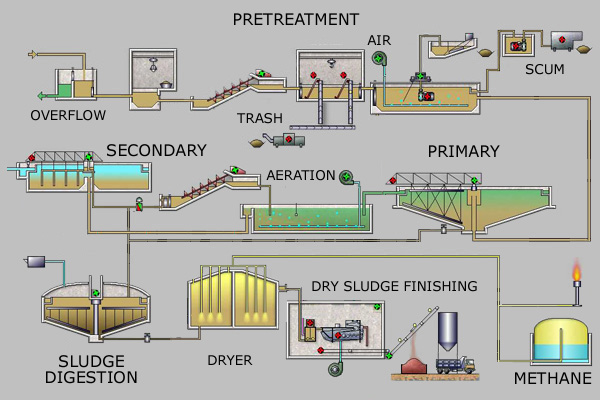


Figure : Traditional Wastewater Treatment Plant Process.34 Description: Pretreatment removes large degree; primary treatment removes nutrients and organic solids; secondary treatment removes fine and ultrafine solids; water is released into the environment after secondary treatment; solids go through further reduction in sludge digestion (also called anaerobic digestion) where biogas/methane is produced; solids are dried and either landfilled or spread over farm fields.

## Environmental and Human Health Effects of CEC

A large gap still exists in understanding CEC’s health effects on humans and the environment. With thousands of CEC and multiple sources for each, the task of determining health risk seems daunting. However, there has been some progress in a few areas. Hospitals are well known as breeding grounds for antibiotic-resistant bacteria because of the volume of antibiotics used in that setting. Similarly, bacteria in sediments downstream of WWTPs show an increase in antibiotic-resistant gene expression because of antimicrobials and antibiotics that escape treatment at the plants.35,36

Fish and other aquatic organisms are prone to bioaccumulation and are particularly sensitive to the health effects of CEC.31,37,38 Concentrations as low as parts per billion or even trillion influence how their endocrine systems produce hormones to support metabolism, growth, tissue function, reproduction, and more.39–41 The results are feminization of male fish, reduced mating behavior, and increased predator avoidance behavior (i.e., easier for prey to be eaten), making for a very imbalanced ecosystem.31,37–46

There are few studies on the health effects of CEC in humans. Results from health studies using model organisms do not always translate well to how CEC will affect humans. Exposure levels and health responses may not have linear correlations, making the health impact data confusing and difficult for scientists to interpret.

CEC Concentrations in WWTPs

Concentrations among the different contaminants are highly variable, and concentrations of individual contaminants can have wide ranges. For example, caffeine (classified as a pharmaceutical and personal care product [PPCP]) was found to have an influent concentration of 0.103-59.408 micrograms per liter (µg/L), whereas amoxicillin (PPCP) had an influent concentration of only 0.258-0.264 µg/L.2,9,13,14,29,30,47–54 Effluent concentrations were just as variable.

There are multiple reasons for concentration variability:

* Different compounds have different uses and those uses have varying potency requirements.
* Different seasons can result in lower or higher concentrations.
* Population variations can change contaminant concentrations.
* Location and varying cultural uses of different CEC can influence CEC concentrations in WWTPs.
* The available data for some compounds were more limited than others.

Tables 1-4 in Appendix A summarize the concentration of each identified CEC in WWTP influent (wastewater going into the treatment plant) and effluent (treated wastewater leaving WWTPs). The contaminants were classified into four categories to help define the intended use of the CEC:

* Agricultural Chemicals
* Industrial Chemicals
* Microplastics
* Pharmaceuticals and Personal Care Products (PPCP)

Treatment Technologies

The varying chemistries of CEC require many different treatment types. Removal rates in traditional wastewater treatment range from not effective (-100[[1]](#footnote-1) to 30% removal efficiency) to very effective (90–100% removal efficiency) depending on the specific CEC. For example, whole wastewater treatment plant technology mentioned in Biel-Maeso et al. was only somewhat effective at removing DEET from wastewater, but was very effective in removing sunscreen.55

Wastewater treatment plants were not designed to remove CEC. They were designed to remove excess nutrients and pathogens. Implementation of these practices, as well as drinking water treatment practices, made a significant improvement in overall public health from the mid-1800s to early 1900s.56

Some papers noted the location of the WWTPs being tested. If a location was listed in the paper, it is also noted in the data tables in Appendix A. Locations were noted from every continent except Antarctica, which shows that CEC contamination and treatment is a global issue.

Most treatment technologies are only at an experimental/laboratory scale. Although those treatments are very effective in removing CEC, they are at least 10 to 30 years from being commercially available. In addition, treatment techniques often only focus on removing a single contaminant from deionized water or simulated wastewater. Real-world treatment technologies will need to manage a mixture of contaminants with a wastewater matrix that can vary in composition from location to location, as well as between seasons and even hours to days. Furthermore, new treatment methods can be a significant financial burden to the communities wishing to implement them. These observations indicate the need to fund further research that develops and matures cost-effective technologies that meet the needs of communities.

In the data tables in Appendix B, treatment technologies were categorized as:

* established and in use,
* commercially available but not in common use (meaning not commonly used for municipal wastewater treatment),
* pilot/field scale, and
* experimental/laboratory scale testing.

In Appendix A, Tables 1–4, influent concentrations can be compared to effluent concentrations for each contaminant to generally assess traditional WWTP removal efficiencies.

Only the information provided in Appendix B, Tables 5–20, about the effectiveness of traditional WWTP technologies is accurate and has been normalized for some error bias. In Tables 5–8, treatment technologies for different contaminants are separated into the same categories as Tables 1–4. Some treatment methods for matrixes other than wastewater, such as drinking water, groundwater, and soil, are included because there may be treatment parallels drawn from them or there were no wastewater treatment technologies available for a specific contaminant but there was one in a different matrix. Table 9 shows treatment technologies specifically for PFAS. Tables 10–20 group treatment technologies by their commercial availability.

# Legislative Actions

Although many states are starting to realize the dangers of CEC, others have failed to see the hazards. Multiple states have focused on the elimination of these contaminants in public drinking water supplies or in firefighting foams, but have yet to enact regulations for WWTPs.57

Several companies are being sued for their continued discharging of these contaminants. Communities believe that these companies are aware of the concerns and yet do nothing. One example is 3M in Alabama. Litigants believe that the company has known for years that wastewater treatment does nothing to reduce perfluorooctanesulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) (two types of PFAS) concentrations in water that is released into the environment and the community’s drinking water source. A number of groups alleging injury and personal injury from the water supply are suing 3M, but 3M alleges these claims are barred by statutes of limitation as well as a lack of duty owed to the plaintiffs.[[2]](#footnote-2) Because of the lack of laws and regulations, people affected by CEC have limited actions to take.

Whether it is the cost of the water treatment that would be required to treat more CEC or the changes that would have to be enacted, many states are lagging in efforts to monitor contaminant levels or set wastewater treatment standards. Although states have started to enact legislation to address CEC in WWTPs, none have set maximum contaminant levels. The most any state has done is set up a task force or called for a review of these chemicals.[[3]](#footnote-3) Some states have proposed legislation to start a task force or review, but many of the bills have failed at introduction or have become stale in the chambers of their respective houses, never to make it out.[[4]](#footnote-4) In order to address the problem of CEC in WWTPs, more states will need to conduct research on and set standards for these contaminants.

## U.S. State Legislation at a Glance

Appendix C provides a detailed list of state regulations for contaminants of emerging concern and is organized into the following categories:

* Enacted
* Introduced but not enacted
* Failed
* Firefighting foam regulations
* No regulations
* Federal litigation pending

A short list that shows states and the status of bills on wastewater (or other as noted) regulations is provided in this section. Court cases are also included at the end of this list.

California

* 2017 Legis. Bill Hist. CA S.B. 1422 [drinking water, enacted]

Hawaii

* 2017 Bill Text HI H.B. 2042 [failed]

Illinois

* 110 ILCS 425/21 [codified]

Maine

* 2019 Bill Text ME E.O. 5 [enacted]

Michigan

* 2018 Bill Text MI H.B. 6245 [failed]

Minnesota

* 2019 Bill Text MN H.B. 2032 [introduced]
* 2019 Bill Text MN S.B. 2201 [introduced]
* 2015 Bill Text MN H.B. 846 [vetoed]
* 2015 Bill Text MN S.B. 1305 [failed]

New Hampshire

* N.H. Rev. Stat. Ann. § 126-A:79-a [enacted and codified]
* 2017 Bill Text NH H.B. 485 [failed]

North Carolina

* 2019 Bill Text NC S.B. 518 [introduced]

Pennsylvania

* 2019 Bill Text PA S.B. 582 [failed]
* 2019 Bill Text PA H.B. 1226 [introduced]

Vermont

* 2019 Bill Text VT H.B. 98 [introduced]
* 2019 Bill Text VT S.B. 49 [introduced]
* 2019 Bill Text VT H.B. 263 [introduced]

Cases

* *Rhodes v. E.I. Du Pont de Nemours & Co.*, 657 F. Supp. 2d 751 (S.D. W. Va. 2009)
* *King v. W. Morgan-East Lawrence Water & Sewer Auth.*, No. 5:17-cv-01833-AKK, 2019 U.S. Dist. LEXIS 40191 (N.D. Ala. Mar. 13, 2019)
* *W. Morgan-East Lawrence Water & Sewer Auth. v. 3M Co.*, 208 F. Supp. 3d 1227 (N.D. Ala. 2016)
* *Tenn. Riverkeeper, Inc. v. 3M Co.*, 234 F. Supp. 3d 1153 (N.D. Ala. 2017)

# Appendix A: Contaminants of Emerging Concern in Wastewater Treatment Plants Tables

Table : CEC in WWTPs: Agricultural Chemicals.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Contaminant | Influent Concentration | Effluent Concentration | Intended Function | Also detected in | Location, if noted | References |
| 2,4-dichlorophenoxyacetic acid | 0.0885 µg/L | ND-0.751 µg/L | pesticide |  |  | 58 |
| 3-amino-2-chloropyridine | 64,200-321,300 µg/L | 1,284-6,424 µg/L | pesticide |  |  | 59 |
| 4-chloro-2-methylphenoxyacetic acid |  | 0.001-0.007 µg/L | pesticide |  |  | 60 |
| acetamiprid | 0.0037-0.050 µg/L | 0.003-1.465 µg/L | pesticide | surface water | Australia, Spain | 4,48,61,62 |
| acetochlor |  | ND-0.006 µg/L | herbicide |  |  | 29 |
| aldrin | 5,000 µg/L | 500-1,600 µg/L | pesticide |  |  | 59 |
| atrazine | 0.00124-90,000 µg/L | 0.004-8,100 µg/L | pesticide | groundwater, surface water | France, Spain, Switzerland, Western Balkan Region | 2,29,49,59,60,62 |
| azoxystrobin |  | ND-0.090 µg/L | fungicide |  |  | 48 |
| carbaryl |  | ND-0.010 µg/L | insecticide |  |  | 29 |
| climbazole | 0.475 µg/L | 0.312 µg/L | pesticide |  |  | 62 |
| clothianidin | 0.1497 µg/L |  | pesticide | surface water | Australia | 4,61 |
| clotrimazole | 0.012-0.080 µg/L | ND-0.009 µg/L | pesticide |  | Greece | 49,62 |
| daidzein |  | ND | phytoestrogen | soybeans and other legumes |  | 29 |
| diazinon | 0.684-10,000 µg/L | 0.007-100 µg/L | pesticide |  | Spain | 49,59 |
| dicamba |  | 0.116-0.184 µg/L | pesticide |  |  | 62 |
| diuron | 0.0284-2.5261 µg/L | 0.002-2.53 µg/L | pesticide |  | France, Spain, Switzerland | 48,49,62 |
| fluconazole | 0.034-0.583 µg/L | 0.028-23.324 µg/L | pesticide |  |  | 62 |
| imidacloprid | 0.002-0.0547 µg/L | 0.002-0.789 µg/L | pesticide | surface water | Spain, USA, Greece, Australia | 4,48,61,62 |
| irgarol | 0.006 µg/L | 0.010-0.200 µg/L | pesticide |  |  | 62 |
| malathion | 10,000-70,000 µg/L | 400-35,000 µg/L | pesticide |  |  | 59 |
| mecoprop | 0.106-0.170 µg/L | 0.002-0.870 µg/L | pesticide | surface water | Slovenia, Croatia | 9,29,62 |
| methiocarb | 0.00126-0.10531 µg/L | 0.00473-0.01492 µg/L | pesticide | groundwater, surface water | Spain | 4,61 |
| methomyl | 18,000 µg/L | 5,940 µg/L | pesticide |  |  | 59 |
| metolachlor |  | ND | herbicide |  |  | 29 |
| prochloraz | 0.0265-0.0632 µg/L | 0.0029-0.0591 µg/L | pesticide |  |  | 62 |
| propiconazole | 0.001-0.086 µg/L | 0.001-1.815 µg/L | pesticide |  |  | 62 |
| pyrimethanil |  | ND-0.051 µg/L | fungicide |  |  | 48 |
| simazine |  | 1.990 µg/L | terbuthylazine metabolite | groundwater, surface water |  | 2 |
| tebuconazole | ND-1.89 µg/L | ND-0.6911 µg/L | fungicide |  | Greece, Spain | 48,49,62 |
| terbutryn | 0.005-0.1829 µg/L | ND-0.390 µg/L | pesticide |  |  | 48,62 |
| thiacloprid | ND | 0.006 µg/L | pesticide | surface water | Australia | 4,61,62 |
| thiamethoxam | ND |  | pesticide | surface water | Vietnam, Australia | 4,61 |

Table : CEC in WWTPs: Industrial Chemicals.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Contaminant | Influent Concentrations | Effluent Concentration | Intended Function | Also detected in | Locations, if noted | References |
| 2-(4-nonylphenoxy)ethan-1-ol | 40 µg/L | 0.06-70 µg/L | plasticizer |  |  | 63 |
| 2-(4-octylphenoxy)ethan-1-ol | 0.08-0.4 µg/L |  | plasticizer |  |  | 63 |
| 2,2’-methylenediphenol bis2 |  | 0.00494-0.0364 µg/L | intermediate compound | surface water | Slovenia, Croatia | 9 |
| 2,4-dichlorophenol | 22,500 µg/L | 900 µg/L | preservatives |  |  | 59 |
| 2,6-di-tert-butyl-4-methylphenol | 2.42 µg/L |  | additive | surface water, groundwater | USA, Sweden, Greece, Germany | 4,61 |
| 2-[2-(4-nonylphenoxy)ethoxy]ethan-1-ol | 0.1-40 µg/L | 0.07-7 µg/L | plasticizer |  |  | 63 |
| 2-{2-[4-(2,4,4-trimethylpentan-2-yl) phenoxy]ethoxy}ethan-1-ol | 0.03-0.9 µg/L | 0.01-0.8 µg/L | plasticizer |  |  | 63 |
| 4-cumylphenol |  | 0.0519 µg/L | intermediate compound | surface water | Slovenia, Croatia | 9 |
| 4-tert-octylphenol | 0.04-4 µg/L | 0.01-3 µg/L | detergent |  |  | 63 |
| acetanilide |  | ND-0.965 µg/L | additive |  |  | 48 |
| benzotriazole | 1.119-44 µg/L | 0.390-13.7 µg/L | ultraviolet light stabilizers and corrosion inhibitor | groundwater, surface water |  | 2,61 |
| bisphenol a | 0.013-20,000 µg/L | 0.070-17,500 µg/L | plasticizer | groundwater, surface water, treated drinking water | China, France, Greece, USA, Western Balkan Region, Slovenia, Croatia, Brazil | 2,9,13,49,59 |
| bisphenol af |  | 0.0000367-0.0034 µg/L | filler | surface water | Slovenia, Croatia | 9 |
| bisphenol b |  | 0.0271 µg/L | resin | surface water | Slovenia, Croatia | 9 |
| bisphenol e |  | 0.476 µg/L | linings and coatings | surface water | Slovenia, Croatia | 9 |
| bisphenol f |  | 0.00254-0.117 µg/L | linings and coatings | surface water | Slovenia, Croatia | 9 |
| bisphenol s |  | 0.108-0.435 µg/L | linings and coatings | surface water | Slovenia, Croatia | 9 |
| bromodichloromethane |  | 68 µg/L | disinfection by-product | surface water |  | 2 |
| chloroform |  | 320 µg/L | disinfection by-product | surface water |  | 2 |
| 1st-chloromethyl-1H-benzotriazole | 4.33-8.73 µg/L | 10.65-18.05 µg/L | corrosion inhibitor | groundwater, treated drinking water | USA | 64 |
| 2nd-chloromethyl-1H-benzotriazole | 14.85-18.25 µg/L | 27.18-49.18 µg/L | corrosion inhibitor | groundwater, treated drinking water | USA | 64 |
| 3rd-chloromethyl-1H-benzotriazole | 5.18-12.58 µg/L | 14.27-33.87 µg/L | corrosion inhibitor | groundwater, treated drinking water | USA | 64 |
| 4th-chloromethyl-1H-benzotriazole | 3.9-11.5 µg/L | 5.37-7.17 µg/L | corrosion inhibitor | groundwater, treated drinking water | USA | 64 |
| di(2-ethylhexyl) phthalate | 0.003-70.0 µg/L | 0.0001-54.0 µg/L | plasticizer |  | Australia, China, USA | 49 |
| dibromochloromethane |  | 20.25 µg/L | disinfection by-product | surface water |  | 2 |
| di-butyl phthalate | ND-11.8 µg/L | ND-4.13 µg/L | plasticizer |  | Australia, China | 49 |
| dibutyldiphenylphosphate |  | 0.010-0.043 µg/L | fire retardant |  | Norway | 58 |
| di-methyl phthalate | ND-6.49 µg/L | ND-1.52 µg/L | plasticizer |  | Australia, China | 49 |
| hexabromocyclododecane | 0.0012-0.011 µg/L |  | fire retardant |  |  | 61 |
| 4-methyl-benzotriazole | 1.72-10.32 µg/L | 0.76-4.16 µg/L | corrosion inhibitor | groundwater, treated drinking water | USA | 64 |
| 5-methyl-benzotriazole | 0-13.23 µg/L | 0.8-1.4 µg/L | corrosion inhibitor | groundwater, treated drinking water | USA | 64 |
| methyl paraben |  | 0.0118-1.91 µg/L | preservatives | surface water | Slovenia, Croatia | 9 |
| n-nitrosodimethylamine | 0.183-8.23 µg/L | 0.400 µg/L | disinfection by-product | groundwater, surface water |  | 2,61 |
| nonylphenol | 0.02-101.6 µg/L | 10-335 µg/L | surfactant | groundwater, surface water | China, France, Germany, Greece, Italy, Spain, USA, Western Balkan Region | 2,29,49,63 |
| perfluorobutanoic acid | 0.00005-0.265 µg/L |  | PFAS |  |  | 61 |
| perfluorohexanoic acid | 1-348 ng/L |  | PFAS |  |  | 61 |
| perfluorooctanesulfonic acid |  | 0.042-0.635 µg/L | PFAS | surface water, treated drinking water, groundwater, sludge/biosolids | Spain, Italy, Germany, China, India, Brazil, USA | 2,8 |
| perfluorooctanoic acid |  | 0.010-0.068 µg/L | PFAS | surface water | Spain, Italy, Germany, China, India, Brazil, USA | 2,8 |
| perfluoropentanoic acid | 0.0005-1.52 µg/L |  | PFAS |  |  | 61 |
| tetrabromobisphenol a | ND-0.041 µg/L |  | fire retardant |  |  | 61 |
| tributylphosphat |  | 0.154-2.099 µg/L | fire retardant |  | Norway | 58 |
| tris(2-chloroethyl)phosphate | 0.06-0.50 µg/L | 0.06-2.40 µg/L | fire retardant |  | Germany, Norway | 49,58 |
| tris(2-chloro-isopropyl)phosphate | 0.18-4 µg/L | 0.10-21 µg/L | fire retardant |  | Germany, Norway | 49,58,61 |

Table : CEC in WWTPs: Microplastics.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Influent Concentrations | Effluent Concentration | Intended Function | Also detected in | Location, if noted | Notes | References |
| 0.4-190898 fibers/L | 0.02-81 fibers/L | synthetic textiles | sludge/biosolids, surface water, sediment | France, Finland, Russia, Germany, USA, Canada, South Korea, Italy | some locations have combined sewer and storm water | 10,21–23,25,27,28 |
| ND-71429 particles/L | 0.0008-5000 particles/L | bits broken from larger plastics | surface water, sediment, sludge/biosolids | France, Finland, USA, Sweden, Russia, Australia, Netherlands, Germany, Scotland, Canada, Turkey, South Korea, Italy, China | some locations have combined sewer and storm water | 10–12,15–28,65–68 |
| 1.56-2.7 particulate forms/L | 0.12-0.26 particulate forms/L | additive |  |  |  | 20 |

Table : CEC in WWTPs: Pharmaceuticals and Personal Care Products.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Contaminant | Influent Concentrations | Effluent Concentration | Intended Function | Also detected in | Location, if noted | References |
| 11-nor-9-carboxy-δ9-tetrahydrocannabinol thc-cooh | ND-0.14146 µg/L |  | illicit drug |  | Italy | 69 |
| 17α-ethinylestradiol | ND-0.4507 µg/L | 0.001-17.2 µg/L | steroid, hormone | groundwater, surface water | South Africa, China, France, Germany, Italy, Sweden, USA, Spain, Austria, Portugal, South Korea, | 4,8,49,59–61 |
| 17β-estradiol | 0.002-820 µg/L | 0.001-3.9 µg/L | steroid, hormone | groundwater, surface water | Czech Republic, Sweden, Japan, France, South Korea, China, Germany, Italy, USA, Spain, Austria, Portugal, Slovenia, Croatia | 4,8,9,47,49,59–61 |
| 2-(2h-benzotriazol-2-yl)-4-(2,4,4-trimethyl-2-pentanyl)phenol |  | 0.001-0.011 µg/L | sunscreen |  | Norway | 58 |
| 2-(2h-benzotriazol-2-yl)-4,6-ditertpentylphenol |  | 0.05-0.09 µg/L | sunscreen |  |  | 63 |
| 2-(diphenylmethoxy) acetic acid | 0.0037-0.00379 µg/L | 0.00414-0.0045 µg/L | antihistamine | sludge/biosolids |  | 14 |
| 2,4-dihydroxybenzophenone |  | 0.0361-0.563 µg/L | metabolite of benzophenone | surface water | Slovenia, Croatia | 47 |
| 2-ethylhexyl-4-methoxycinnamate | 0.0155-1.29 µg/L | 0.0047-0.505 µg/L | sunscreen | groundwater, surface water | China, Norway, Japan, Spain, Hong Kong | 61 |
| 2-ethyl-hexyl-4-trimethoxycinnamate | 0.309-0.601 µg/L | 0.126-0.347 µg/L | sunscreen |  | Hong Kong | 4 |
| 2-ethylidene-1,5-dimethyl-3,3-diphenylpyrrolidine (methadone metabolite) | ND-0.278 µg/L | 0.0382-0.160 µg/L | illicit drug | sludge/biosolids | Italy | 14,50,69 |
| 2-hydroxy-4-methoxybenzophenone |  | 0.00247-0.0485 µg/L | metabolite of benzophenone | surface water | Slovenia, Croatia | 9 |
| 3-(4-methylbenzylidene)camphor | 0.5-4 µg/L | 0.05-2 µg/L | sunscreen |  |  | 63 |
| 3,4-Methylenedioxyamphetamine | 0.002-0.491 µg/L | 0.0128-0.0344 µg/L | illicit drug | sludge/biosolids |  | 14 |
| 4-acetamidoantipyrine |  | ND-26.705 µg/L | metabolite of aminopyrine |  |  | 30,48 |
| 4-formylaminoantipyrine |  | 0.0146-89.478 µg/L | metabolite of aminopyrine |  |  | 30,48 |
| 4-hydrosybenzophenone |  | 0.0075-29.9 µg/L | metabolite of benzophenone | surface water | Slovenia, Croatia | 9 |
| 4-methylaminoantipiryne |  | ND-6.732 µg/L | metabolite of aminopyrine |  |  | 47 |
| 4-methyl-benzilidine-camphor | 0.169 µg/L | 0.043 µg/L | sunscreen |  | Hong Kong | 30,48 |
| acesulfame | 0.92-1.23 µg/L | 0.0046-2,500 µg/L | artificial sweetener | groundwater, surface water, sludge/biosolids |  | 2,14,48,70 |
| acetaminophen | 1.57-113.281 µg/L | ND-7.847 µg/L | nonsteroidal anti-inflammatory | surface water | Germany, South Korea, Spain | 6,14,29,47–49,51 |
| acetylsalicylic acid |  | 1.5 µg/L | nonsteroidal anti-inflammatory | surface water | Germany | 6 |
| alprazolam | 0.00589-0.00624 µg/L | 0.00459-0.0062 µg/L | mood stabilizer | sludge/biosolids |  | 14 |
| amitriptyline |  | 0.037-0.168 µg/L | mood stabilizer |  |  | 30,48 |
| amoxicillin | 0.258-0.264 µg/L | 0.064-0.068 µg/L | antibiotic |  | Hong Kong | 47 |
| amphetamine | ND-0.55 µg/L | ND-0.0035 µg/L | illicit drug |  | Italy | 14,50,52 |
| ampicillin | ND-1.805 µg/L | ND-0.498 µg/L | antibiotic |  | Greece | 47 |
| androstenedione | ND-0.097 µg/L | ND-0.045 µg/L | steroid, hormone |  | Barbados | 50,53,70 |
| antipyrine |  | 0.030-1.254 µg/L | analgesic |  |  | 30,48 |
| aripiprazole | 0.00543-0.00558 µg/L | 0.00169-0.0103 µg/L | mood stabilizer | sludge/biosolids |  | 14 |
| aspartame | 0.08-0.18 µg/L | 0.08-0.14 µg/L | artificial sweetener | sludge/biosolids |  | 14 |
| atenolol | ND-33.1 µg/L | 0.13-7.60 µg/L | beta blocker | surface water, sludge/biosolids | Korea, Spain, Switzerland, UK, Western Balkan Region, Italy | 2,14,30,48,49,51,52 |
| azithromycin | ND-6.81 µg/L | 0.0004-1.22 µg/L | antibiotic | groundwater, surface water, sludge/biosolids | Italy, Slovakia, Portugal, Vietnam, China, Spain, Japan, Canada | 4,14,30,48,61 |
| benzophenone | 0.007-7 µg/L | 0.003-60 µg/L | sunscreen |  | Korea, Spain, Norway | 49,61,63 |
| benzoylecgonine | ND-71.023 µg/L | ND-0.0981 µg/L | cocaine metabolite |  | Italy | 14,50,52,69 |
| benzyl paraben |  | 0.0236-0.676 µg/L | preservatives | surface water | Slovenia, Croatia | 9 |
| betaxolol |  | 0.19 µg/L | beta blocker | surface water | Germany | 6 |
| bezafibrate | 0.015-1.39 µg/L | 0.002-0.106 µg/L | lowers lipid levels | surface water | Spain, South Korea, UK, Western Balkan Region, China, Germany | 6,30,48,49,54 |
| bisoprolol |  | 0.37 µg/L | beta blocker | surface water | Germany | 6 |
| bupropion | 0.0725-0.147 µg/L | 0.0341-0.221 µg/L | mood stabilizer | sludge/biosolids |  | 14 |
| butyl methoxydibenzoylmethane | 0.289 µg/L | 0.147 µg/L | sunscreen |  | Hong Kong | 47 |
| butylparaben | 0.015-0.170 µg/L | 0.001-0.003 µg/L | preservatives |  | China | 47 |
| caffeine | 0.103-59.408 µg/L | ND-49.6 µg/L | stimulant | groundwater, surface water, treated drinking water, sediment | China, Greece, South Korea, Spain, UK, Brazil, Italy, Barbados, Slovenia, Croatia | 2,9,13,14,29,30,48–54 |
| calaxilid fragrance | 2.56-4.52 µg/L |  | fragrance |  | Korea | 47 |
| carazolol |  | 0.12 µg/L | beta blocker | surface water | Germany | 6 |
| carbamazepine | 0.040-15.78 µg/L | 0.00049-7.57 µg/L | anticonvulsant | groundwater, surface water, sludge/biosolids | China, Greece, South Korea, Spain, UK, Western Balkan Region, Germany, Italy, Barbados, Slovenia, Croatia | 2,6,9,14,29,30,47–54,60,61,70,71 |
| carbamazepine epoxide | 0.156-0.228 µg/L | ND-0.384 µg/L | metabolite of carbamazepine |  |  | 30,48,50 |
| carbendazim |  | 0.053-0.335 µg/L | fungicide |  |  | 48 |
| cefalexin | 0.035-0.045 µg/L | ND | antibiotic |  | Hong Kong | 47 |
| cefotaxime |  | ND-0.539 µg/L | antibiotic |  |  | 48 |
| celestolide | 0.006-0.2 µg/L | 0.0013-0.2 µg/L | fragrance |  | Norway | 58,63 |
| chloramphenicol | 0.011-0.262 µg/L | ND-0.297 µg/L | antibiotic |  | Hong Kong, Spain, China | 47,54 |
| ciprofloxacin | ND-3.35 µg/L | ND-1.788 µg/L | antibiotic |  | Italy | 47,48,51,52,61 |
| citalopram | 0.0594-0.133 µg/L | 0.021-0.792 µg/L | mood stabilizer | sludge/biosolids |  | 14,30,48 |
| clarithromycin | ND-27.4 µg/L |  | antibiotic | groundwater, surface water | Italy, Slovakia, Vietnam, Spain, China, USA, Japan, Germany, Israel, Switzerland | 4,30,48,52,61,71 |
| clenbuterol |  | 0.08 µg/L | beta blocker | surface water | Germany | 6 |
| clofibric acid | ND-0.74 µg/L | ND-0.33 µg/L | lowers lipid levels | surface water | China, Greece, South Korea, Spain, Sweden, UK, Western Balkan Region | 6,49,54 |
| clomipramine |  | ND-0.029 µg/L | mood stabilizer |  |  | 48 |
| clopidogrel | 0.0314-0.0355 µg/L | 0.0218-0.0237 µg/L | blood thinner | sludge/biosolids |  | 14 |
| clopidogrel carboxylic acid | 0.124-0.16 µg/L | 0.116-0.194 µg/L | metabolite of clopidogrel | sludge/biosolids |  | 14 |
| cocaethylene | 0.00394-0.00484 µg/L |  | illicit drug |  |  | 14 |
| cocaine | ND-0.860 µg/L | ND-0.102 µg/L | illicit drug | sludge/biosolids | Italy | 14,50,52,69 |
| codeine | 0.01729-2.208 µg/L | 0.125-0.17 µg/L | narcotic | sludge/biosolids | Italy | 14,50,69 |
| cotinine | 1.43-2.7 µg/L | ND-0.319 µg/L | metabolite of nicotine |  |  | 14,29,30,48 |
| crotamiton |  | ND-4.5 µg/L | itch reliever | groundwater, surface water |  | 2 |
| cyclamate |  | 16.6 µg/L | artificial sweetener | groundwater, surface water |  | 2 |
| cyclophosphamide |  | ND-0.049 µg/L | chemotherapy | surface water | Germany | 6,48 |
| DEET | 0.1-3.19 µg/L | <LOD-650 µg/L | pesticide |  | China, Norway | 29,47–49,54,58,60,63 |
| desacetyl citalopram | 0.0128-0.0554 µg/L | 0.0793-0.118 µg/L | metabolite of citalopram | sludge/biosolids |  | 14 |
| desacetyl diltiazem | 0.473-0.483 µg/L | 0.294-0.327 µg/L | metabolite of diltiazem | sludge/biosolids |  | 14 |
| diatrizoic acid |  | 0.116-5.487 µg/L | diagnostic agent | groundwater, surface water |  | 2,48 |
| diazepam | 0.00338-0.00379 µg/L | 0.00173-0.367 µg/L | mood stabilizer | surface water, sludge/biosolids | Germany | 6,14,48 |
| diclofenac | ND-0.0942 µg/L | ND-0.0055 µg/L | nonsteroidal anti-inflammatory | groundwater, surface water, sludge/biosolids | Ireland, Spain, Greece, Italy, Portugal, Costa Rica, Greece, South Korea, Switzerland, Sweden, UK, Western Balkan Region, Australia, Canada, China, France, Finland, Germany, Pakistan, Croatia, Taiwan, Luxembourg, USA, Belgium, Slovenia, Croatia | 4,6,7,9,14,32,47,49,54,61,71,72 |
| diclofenac transformation product 1 |  | 0.781-5.72 µg/L | nonsteroidal anti-inflammatory | surface water | Slovenia, Croatia | 9 |
| dihydrocodeine | 0.311-0.347 µg/L | 0.026-0.028 µg/L | narcotic |  |  | 50 |
| dihydroxy carbamazepine | 1.02-1.128 µg/L | 0.599-0.697 µg/L | metabolite of carbamazepine |  |  | 50 |
| diltiazem | 0.105-1.0194 µg/L | 0.053-0.194 µg/L | antihypertensive | sludge/biosolids |  | 14 |
| dimethylaminophenazone |  | 1.0 µg/L | nonsteroidal anti-inflammatory | surface water | Germany | 6 |
| diphenhydramine | 0.227-0.462 µg/L | 0.0857-0.5888 µg/L | antihistamine |  |  | 14 |
| enrofloxacin | 0.003-0.1 µg/L |  | antibiotic |  |  | 61 |
| ephedrine | 1.554-1.678 µg/L | 0.069-0.075 µg/L | stimulant |  |  | 50 |
| erythromycin | ND-10.0 µg/L | ND-2.84 µg/L | antibiotic | groundwater, surface water | Hong Kong, Greece, Slovakia, China, Vietnam, Spain, UK, Western Balkan Region, USA, France, Israel, Austria, Italy | 4,29,47,48,48,49,52,61,71 |
| estriol | 0.125-0.80 µg/L | ND-0.010 µg/L | steroid, hormone |  | Czech Republic, China, South Korea | 47,49 |
| estrone | ND-0.224 µg/L | ND-1.98 µg/L | steroid, hormone | groundwater, surface water | France, Czech Republic, China, South Korea, Sweden, Japan, Germany, Italy, Sweden, USA, Spain, Portugal, Barbados, Slovenia, Croatia, Austria | 2,4,8,9,47,49,50,53,60,61,70 |
| ethylhexyl salicylate | 0.093 µg/L | 0.008 µg/L | sunscreen |  | Hong Kong | 47 |
| ethylhexylmethoxycinnamate |  | 0.008-0.064 µg/L | sunscreen |  | Norway | 58 |
| ethylparben | 0.02-2 µg/L | 0.002-2 µg/L | antifungal |  |  | 63 |
| famotidine |  | 0.056-0.585 µg/L | antacid |  |  | 30,48 |
| fenofibric acid |  | ND-0.948 µg/L | lowers lipid levels |  |  | 6,30,48 |
| fenoprofen |  | ND | nonsteroidal anti-inflammatory | surface water | Germany | 6 |
| fenoterol |  | 0.060 µg/L | beta blocker | surface water | Germany | 6 |
| fentanyl | ND | ND | narcotic |  |  | 50 |
| flumequine |  | 0.013-0.037 µg/L | antibiotic |  |  | 30 |
| fluoxetine | 0.017-0.6 µg/L | ND-0.56 µg/L | mood stabilizer |  |  | 14,30,48 |
| furosemide |  | 0.042-8.84 µg/L | diuretic |  |  | 30,48 |
| galaxolide | 0.03-25 µg/L | 0.02-10 µg/L | fragrance |  | Spain, Western Balkan Region, Norway | 63 |
| gemfibrozil | 0.10-17.1 µg/L | <0.0025-5.24 µg/L | lowers lipid levels | groundwater, surface water | Greece, South Korea, Spain, Western Balkan Region, China, Germany, Barbados | 2,6,14,30,47–49,53,54,60,70 |
| gentisic acid (aspirin metabolite) |  | 0.59 µg/L | metabolite of aspirin | surface water | Germany | 6 |
| homosalate | 0.151 µg/L | 0.031 µg/L | sunscreen |  | Hong Kong | 47,63 |
| hydrochlorothiazide |  | 0.724-4.801 µg/L | diuretic |  |  | 30,48 |
| hydrocodone | 0.014-0.210 µg/L | 0.0086-0.91 µg/L | narcotic | sludge/biosolids |  | 14 |
| ibuprofen | 0.004-603 µg/L | ND-55 µg/L | nonsteroidal anti-inflammatory | surface water, sludge/biosolids | UK, Spain, Greece, China, South Korea, Sweden, USA, Western Balkan Region, Germany, Barbados, Slovenia, Croatia | 6,9,14,47,49–51,53,60,70 |
| ifosfamide |  | 0.029-2.9 µg/L | chemotherapy | surface water | Germany | 6,30 |
| imazalil |  | ND-0.222 µg/L | fungicide |  |  | 48 |
| indomethacin | 0.080-0.200 µg/L | ND-0.60 µg/L | nonsteroidal anti-inflammatory | surface water | China, Germany | 6,48,51,54 |
| isoamyl p-methoxycinnamate | 0.043 µg/L | 0.024 µg/L | sunscreen |  | Hong Kong | 47 |
| isoproturon |  | ND-0.304 µg/L | pesticide |  |  | 48 |
| ketamine | ND | ND | illicit drug |  |  | 50 |
| ketoprofen | 0.004-8.56 µg/L | ND-3.92 µg/L | nonsteroidal anti-inflammatory | surface water | China, South Korea, Spain, UK, Western Balkan Region, Germany, Slovenia, Croatia | 6,9,30,48,49,51 |
| ketorolac |  | 0.014 µg/L | nonsteroidal anti-inflammatory |  |  | 30 |
| lamotrigine | 0.013-1.11 µg/L |  | anticonvulsant |  |  | 61 |
| levofloxacin | 0.18 µg/L | 0.01 µg/L | antibiotic |  | UK | 47 |
| lincomycin |  | 0.035-0.634 µg/L | antibiotic |  |  | 30,48 |
| lindane | 100 µg/L | 1 µg/L | insecticide |  |  | 59 |
| lorazepam | 0.0162-0.0203 µg/L | 0.0642-0.0784 µg/L | anticonvulsant | sludge/biosolids |  | 14 |
| MDMA | 0.0027-0.185 µg/L | 0.0005-0.096 µg/L | illicit drug | sludge/biosolids |  | 14 |
| meclofenamic acid |  | ND | nonsteroidal anti-inflammatory | surface water | Germany | 6 |
| mefenamic acid | 0.017-1.27 µg/L | 0.005-0.39 µg/L | nonsteroidal anti-inflammatory |  | Korea, Spain, UK, China | 49,51,54 |
| mepivacaine |  | 0.014-0.410 µg/L | anesthetic |  |  | 30,48 |
| metalaxyl |  | ND-0.162 µg/L | fungicide |  |  | 48 |
| metformin | ND-10 µg/L |  | antidiabetic |  |  | 61 |
| methadone | 0.00328-0.126 µg/L | 0.0173-0.044 µg/L | illicit drug | sludge/biosolids | Italy | 14,50,69 |
| methamphetamine | ND-2 µg/L | ND-0.570 µg/L | illicit drug | sludge/biosolids | Italy | 14,50,52 |
| methyl diethanolamine | 0.00233-0.00329 µg/L | 0.00027-0.00112 µg/L | illicit drug | sludge/biosolids |  | 14 |
| methyl dihydrojasmonate | 6 µg/L | 0.4-7 µg/L | fragrance |  |  | 63 |
| methylenedioxymethamphetamine | ND-0.151 µg/L | ND | illicit drug |  | Italy | 52 |
| methylparaben | 0.0368-10 µg/L | 0.008-3 µg/L | preservatives |  | Spain, USA | 47,63 |
| metoclopramide |  | 0.012-0.075 µg/L | gut motility stimulator |  |  | 48 |
| metoprolol | 0.002-1.52 µg/L | 0.003-2.2 µg/L | beta blocker |  | China, South Korea, Spain, Switzerland, UK, Germany | 6,30,49,54,71 |
| metronidazole |  | ND-0.068 µg/L | antibiotic |  |  | 30,48 |
| morphine | 0.01503-0.647 µg/L | 0.016-0.0339 µg/L | narcotic | sludge/biosolids | Italy | 14,50,69 |
| musk ketone |  | 0.01-3 µg/L | fragrance |  |  | 63 |
| nadilixic acid |  | ND-0.932 µg/L | antibiotic |  |  | 48 |
| nadolol |  | 0.016-0.060 µg/L | beta blocker | surface water | Germany | 6,30 |
| naproxen | 0.002-52.9 µg/L | ND-2.19 µg/L | nonsteroidal anti-inflammatory | surface water, sludge/biosolids | Spain, Greece, South Korea, Spain, Sweden, UK, Western Balkan Region, Germany, Slovenia, Croatia | 6,9,14,30,47–51,60,70 |
| nicotine | 1.177-17 µg/L | ND-21 µg/L | stimulant |  |  | 14,30,48 |
| nicotinic acid (Vitamin B) |  | 1.83-4.738 µg/L | vitamin |  |  | 30 |
| norcocaine | 0.00292-0.05 µg/L | 0.00102-0.00507 µg/L | illicit drug |  |  | 14 |
| nordiazepam | 0.00404-0.00530 µg/L | 0.00369-0.00453 µg/L | anticonvulsant | sludge/biosolids |  | 14 |
| norfloxacin | 29-861 ng/L | <LOD-523 ng/L | antibiotic |  | Hong Kong | 47,48 |
| norfluoxetine | 0.0099-0.0142 µg/L | 0.0039-0.026 µg/L | metabolite of fluoxetine |  |  | 14 |
| nor-quetiapine | 0.0661-0.071 µg/L | 0.0743-0.0823 µg/L | mood stabilizer | sludge/biosolids |  | 14 |
| norsertraline | 0.0143-0.0711 µg/L | 0.0099-0.0544 µg/L | metabolite of sertraline | sludge/biosolids |  | 14 |
| nor-verapamil | 0.00888-0.0148 µg/L | 0.0058-0.0203 µg/L | metabolite of verapamil | sludge/biosolids |  | 14 |
| octinoxate | 0.05-30 µg/L | 0.01-7 µg/L | sunscreen |  |  | 63 |
| octocrylene | 0.04-4 µg/L | 0.01-0.7 µg/L | sunscreen |  | Norway, Hong Kong | 47,58,63 |
| octyl dimethyl-p-aminobenzoic acid | 0.138 µg/L | 0.056 µg/L | sunscreen |  | Hong Kong | 47 |
| octylphenol | <0.2-8.7 µg/L | 0.004-1.3 µg/L | surfactant |  | China, France, Germany, Italy, Spain, UK, USA | 49 |
| ofloxacin | 0.138-1.263 µg/L | 0.068-2.186 µg/L | antibiotic |  | Italy, Hong Kong | 47,48,51,52 |
| o-hydroxyhippuric acid (aspirin metabolite) |  | ND | nonsteroidal anti-inflammatory | surface water | Germany | 6 |
| oxycodone | ND-0.220 µg/L | 0.020-0.053 µg/L | narcotic | sludge/biosolids | India | 14,47,50 |
| oxydiazepam | 0.00652-0.00843 µg/L | 0.00772-0.00987 µg/L | mood stabilizer | sludge/biosolids |  | 14 |
| paracetamol | ND-1.208 µg/L | ND | analgesic |  | Italy | 52 |
| paraxanthine | 9.65-55 µg/L | 0.0164-25 µg/L | stimulant |  |  | 14,30 |
| paraxantine |  | ND-1.589 µg/L | stimulant |  |  | 48 |
| paroxetine | 0.0105 µg/L | 0.0158 µg/L | mood stabilizer | sludge/biosolids |  | 14 |
| pentoxyfilline |  | 0.017-0.286 µg/L | vasodilator |  |  | 48 |
| phantolide | 0.004-0.4 µg/L | 0.002-0.2 µg/L | fragrance |  | Norway | 58,63 |
| phenazone | 20-30 g/d | 5-25 g/d | nonsteroidal anti-inflammatory | surface water | Germany | 6 |
| pravastatin |  | 0.045-0.05 µg/L | lowers lipid levels |  |  | 30 |
| primidone |  | ND-0.42 µg/L | anticonvulsant | groundwater, surface water |  | 2,7,30 |
| progesterone |  | ND-0.20373 µg/L | steroid, hormone | surface water |  | 7 |
| propanolol |  | ND-0.104 µg/L | beta blocker |  |  | 30,48 |
| propiphenazone |  | 0.015-0.038 µg/L | analgesic |  |  | 30 |
| propranolol | 0.060-0.638 µg/L | 0.093-0.388 µg/L | beta blocker | surface water, sludge/biosolids | UK, Germany | 6,14,47 |
| propylparaben | 0.02-3 µg/L | 0.001-0.03 µg/L | preservatives |  | Spain | 47,63 |
| propyphenazone |  | ND-0.061 µg/L | analgesic |  |  | 48 |
| quetiapine | 0.0155-0.0244 µg/L | 0.00098-0.0046 µg/L | mood stabilizer | sludge/biosolids |  | 14 |
| ranitidine |  | 0.231-1.33 µg/L | antacid |  |  | 30,48 |
| roxithromycin | 0.120-0.1264 µg/L | 0.137-0.147 µg/L | antibiotic |  | Hong Kong | 47 |
| saccharin | 13.8-16.4 µg/L | 0.062-55.1 µg/L | artificial sweetener | groundwater, surface water, sludge/biosolids |  | 2,14,48 |
| salbutamol |  | 0.025-0.170 µg/L | beta blocker | surface water | Germany | 6,30 |
| salicylic acid (aspirin metabolite) | 0.58-63.7 µg/L | ND-0.50 µg/L | nonsteroidal anti-inflammatory | surface water | Greece, Spain, UK | 6,49 |
| sertraline | 0.0431-0.0808 µg/L | 0.021-0.0828 µg/L | mood stabilizer | sludge/biosolids |  | 14 |
| sotalol |  | 0.079-0.106 µg/L | treat fast/irregular heartbeats |  |  | 30 |
| sucralose | 2.217-47.5 µg/L | ND-38.8 µg/L | artificial sweetener | groundwater, surface water, sludge/biosolids |  | 2 |
| sulfadiazine |  | 0.040-0.075 µg/L | antibiotic |  |  | 30 |
| sulfamethazine | ND-0.507 µg/L | ND-0.146 µg/L | antibiotic |  | Greece, Hong Kong | 47 |
| sulfamethoxazole | ND-3.1 µg/L | <LOQ-2.6 µg/L | antibiotic | surface water, treated drinking water | France, South Korea, Spain, Sweden, Switzerland, UK, Western Balkan Region, Italy, Barbados | 2,14,29,30,48–50,52,53,60,61,70,71 |
| sulfapyridine |  | 0.095-0.379 µg/L | antibiotic |  |  | 30,48 |
| sulisobenzone | 0.3-6 µg/L | 0.1-2 µg/L | sunscreen |  |  | 63 |
| sulpiride | 0.080-0.250 µg/L | 0.1-0.13 µg/L | mood stabilizer |  | China | 54 |
| terbutalin |  | 0.12 µg/L | beta blocker | surface water | Germany | 6 |
| testosterone |  | ND-178.16 ng/L | steroid, hormone |  |  | 7 |
| tetracycline | 0.017-0.433 µg/L | ND-0.211 µg/L | antibiotic |  | Hong Kong | 47 |
| theophylline |  | ND-0.001613 µg/L | bronchodilator |  |  | 30,48 |
| thiabendazole |  | ND-0.687 µg/L | antifungal |  |  | 48 |
| timolol |  | 0.07 µg/L | beta blocker | surface water | Germany | 6 |
| tolfenamic acid |  | ND | nonsteroidal anti-inflammatory | surface water | Germany | 6 |
| tonalide | 0.05-3 µg/L | ND-2 µg/L | fragrance |  | Spain, Western Balkan Region, Norway | 49,58,63,70 |
| toxalide fragrance | 0.55-1.21 µg/L |  | fragrance |  | Korea | 47 |
| tramadol | 0.168-0.18 µg/L | 0.1-0.115 µg/L | narcotic |  |  | 50 |
| traseolide | 0.02-0.3 µg/L | 0.008-0.3 µg/L | fragrance |  | Norway | 58,63 |
| triclocarban | 0.540-1.15 µg/L | ND-0.049 µg/L | antimicrobial |  | India, USA | 47,70 |
| triclosan | 0.001–86.2 µg/L | 0.01-6.88 µg/L | antimicrobial | groundwater, surface water | USA, South Korea, China, Japan, Spain, UK, Greece, France | 3,5,47,49,50,60,61,63,70 |
| trimethoprim | 0.0057-6.8 µg/L | ND-3.05 µg/L | antibiotic |  | Hong Kong, China, South Korea, Spain, UK, Barbados | 14,29,30,47–51,53,54,60,61 |
| tylosin |  | 0.01-0.025 µg/L | antibiotic |  |  | 29 |
| venlafaxine | 0.336-0.930 µg/L | 0.029-1.8 µg/L | mood stabilizer | sludge/biosolids |  | 14,30,48,60 |
| verapamil | 0.0073-0.0185 µg/L | 0.026-0.0492 µg/L | antihypertensive | sludge/biosolids |  | 14 |
| α-hydroxy alprazolam | 0.0174-0.0214 µg/L | 0.0092-0.0127 µg/L | metabolite of alprazolam | sludge/biosolids |  | 14 |

# Appendix B: Treatment Methods Tables

Table : CEC Treatment Methods: Agricultural Chemicals.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Contaminant | Technique | Technology Status | Media | Purpose | Effectiveness | Relative Cost | References |
| acetamiprid | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | not effective | low monetary cost | 61 |
| alachlor | constructed wetland | commercially available but not in common use | wastewater | destruction | not effective | high monetary cost | 73 |
| atrazine | cerium and hydrogen sulfite-derived reactive species | experimental/laboratory scale testing | wastewater | destruction | somewhat effective | high monetary cost | 74 |
| atrazine | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| atrazine | biofilter (anthracite, sand, activated carbon) | experimental/laboratory scale testing | wastewater | stop continued contamination | not effective |  | 76 |
| atrazine | constructed wetland | commercially available but not in common use | wastewater | destruction | not effective | high monetary cost | 73 |
| atrazine | ozone | commercially available but not in common use | wastewater | destruction | somewhat effective |  | 75 |
| atrazine | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| atrazine | ultraviolet light + hydrogen peroxide | established and in use | wastewater | destruction | effective |  | 75 |
| chlorpyrifos | constructed wetland | commercially available but not in common use | wastewater | destruction | somewhat effective | high monetary cost | 73 |
| clothianidin | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | not effective | low monetary cost | 61 |
| diazinon | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | somewhat effective | high monetary cost | 77 |
| diuron | constructed wetland | commercially available but not in common use | wastewater | destruction | not effective | high monetary cost | 73 |
| diuron | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| diuron | ozone | commercially available but not in common use | wastewater | destruction | very effective |  | 78 |
| diuron | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| endosulfan | constructed wetland | commercially available but not in common use | wastewater | destruction | somewhat effective | high monetary cost | 73 |
| enrofloxacin hydrochloride  (veterinary antibiotic) | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | somewhat effective | high monetary cost | 77 |
| hexachlorobenzene | constructed wetland | commercially available but not in common use | wastewater | destruction | somewhat effective | high monetary cost | 73 |
| imidacloprid | chlorine | established and in use | wastewater | destruction | not effective |  | 79 |
| imidacloprid | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | not effective | low monetary cost | 61 |
| imidacloprid | fluidized-bed reactor - iron and peroxide | experimental/laboratory scale testing | wastewater | destruction | effective |  | 80 |
| imidacloprid | hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective |  | 79 |
| imidacloprid | ultraviolet light + free chlorine | commercially available but not in common use | wastewater | destruction | effective |  | 79 |
| imidacloprid | ultraviolet light + hydrogen peroxide | experimental/laboratory scale testing | wastewater | destruction | effective |  | 79 |
| isoproturon | constructed wetland | commercially available but not in common use | wastewater | destruction | not effective | high monetary cost | 73 |
| isoproturon | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| isoproturon | ozone | commercially available but not in common use | wastewater | destruction | very effective |  | 78 |
| isoproturon | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| metolachlor | biofilter (anthracite, sand, activated carbon) | experimental/laboratory scale testing | wastewater | stop continued contamination | not effective |  | 76 |
| N,N-diethyl-meta-toluamide | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | not effective |  | 75 |
| N,N-diethyl-meta-toluamide | ozone | commercially available but not in common use | wastewater | destruction | somewhat effective |  | 75 |
| N,N-diethyl-meta-toluamide | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| N,N-diethyl-meta-toluamide | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | somewhat effective |  | 75 |
| oxadiazon | hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| oxadiazon | ozone | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| oxadiazon | ultraviolet light | commercially available but not in common use | wastewater | destruction | effective |  | 81 |
| oxadiazon | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | effective |  | 81 |
| oxadiazon | ultraviolet light + ozone | commercially available but not in common use | wastewater | destruction | effective |  | 81 |
| oxadiazon | ultraviolet light + titanium oxide | commercially available but not in common use | wastewater | destruction | effective |  | 81 |
| pentachlorophenol | constructed wetland | commercially available but not in common use | wastewater | destruction | effective | high monetary cost | 73 |
| propachlor | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | effective | high monetary cost | 77 |
| simazine | constructed wetland | commercially available but not in common use | wastewater | destruction | not effective | high monetary cost | 73 |
| triallat | hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| triallat | ozone | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| triallat | ultraviolet light | commercially available but not in common use | wastewater | destruction | effective |  | 81 |
| triallat | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | somewhat effective |  | 81 |
| triallat | ultraviolet light + ozone | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| triallat | ultraviolet light + titanium oxide | commercially available but not in common use | wastewater | destruction | very effective |  | 81 |

Table : CEC Treatment Methods: Industrial Chemicals.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Contaminant | Technique | Technology Status | Media | Purpose | Effectiveness | Relative Cost | References |
| 1,4-dioxane | bioremediation | experimental/laboratory scale testing | groundwater, drinking water | destruction | effective |  | 82 |
| 2,6-Ditert-butyl-4-methylphenol | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | effective | low monetary cost | 61 |
| 4-chlorophenol | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | not effective | high monetary cost | 83 |
| 4-chlorophenol | Zinc + carbon nanotubes + oxygen | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 77 |
| acid orange 2 | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | effective | high monetary cost | 77 |
| acid orange 7 | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | effective | high monetary cost | 77 |
| acid Yellow 36 | ultraviolet light + carbon nanotubes + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | effective |  | 83 |
| acridine | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | effective | high monetary cost | 77 |
| acridine | ultraviolet light + carbon nanotubes + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 83 |
| acridine | hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| acridine | ozone | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| acridine | ultraviolet light | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| acridine | ultraviolet light + hydrogen peroxide | experimental/laboratory scale testing | wastewater | destruction | not effective |  | 81 |
| acridine | ultraviolet light + ozone | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| acridine | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | not effective |  | 81 |
| aniline | cerium and hydrogen sulfite-derived reactive species | experimental/laboratory scale testing | wastewater | destruction | somewhat effective | high monetary cost | 74 |
| azo dye reactive orange 16 | titanium oxide | experimental/laboratory scale testing | wastewater | destruction | effective |  | 84 |
| benzotriazole | constructed wetland | commercially available but not in common use | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| benzotriazole | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | somewhat effective | low monetary cost | 61 |
| benzotriazole | membrane bioreactor | commercially available but not in common use | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| benzotriazole | moving bed biofilm reactor | experimental/laboratory scale testing | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| bisphenol a | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | somewhat effective |  | 75 |
| bisphenol a | ozone | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| bisphenol a | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| bisphenol a | ultraviolet light + hydrogen peroxide | established and in use | wastewater | destruction | effective |  | 75 |
| bisphenol a | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | effective | high monetary cost | 77 |
| bisphenol a | ultrasonication | experimental/laboratory scale testing | wastewater | destruction | effective |  | 85 |
| blue basic dye | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | effective | high monetary cost | 77 |
| butylated hydroxyanisole | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | somewhat effective |  | 75 |
| butylated hydroxyanisole | ozone | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| butylated hydroxyanisole | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| butylated hydroxyanisole | ultraviolet light + hydrogen peroxide | experimental/laboratory scale testing | wastewater | destruction | effective |  | 75 |
| butylated hydroxytoluene | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | somewhat effective |  | 75 |
| butylated hydroxytoluene | ozone | commercially available but not in common use | wastewater | destruction | not effective to effective depending on application |  | 75,81 |
| butylated hydroxytoluene | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| butylated hydroxytoluene | ultraviolet light + hydrogen peroxide | experimental/laboratory scale testing | wastewater | destruction | effective |  | 75,81 |
| butylated hydroxytoluene | hydrogen peroxide | commercially available but not in common use | wastewater | destruction | somewhat effective |  | 81 |
| butylated hydroxytoluene | ultraviolet light | commercially available but not in common use | wastewater | destruction | effective |  | 81 |
| butylated hydroxytoluene | ultraviolet light + ozone | commercially available but not in common use | wastewater | destruction | somewhat effective |  | 81 |
| butylated hydroxytoluene | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | not effective |  | 81 |
| butylbenzyl phthalate | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | somewhat effective |  | 75 |
| butylbenzyl phthalate | ozone | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| butylbenzyl phthalate | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| butylbenzyl phthalate | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| di-2-ethylhexyl phthalate | constructed wetland | commercially available but not in common use | wastewater | destruction | not effective | high monetary cost | 73 |
| dibutyl phthalate | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | effective | high monetary cost | 77 |
| dichloromethane | constructed wetland | commercially available but not in common use | wastewater | destruction | not effective | high monetary cost | 73 |
| dinitrophenol | visible light + carbon nanotubes + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 83 |
| dioctyl phthalate | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | somewhat effective |  | 75 |
| dioctyl phthalate | ozone | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| dioctyl phthalate | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| dioctyl phthalate | ultraviolet light + hydrogen peroxide | experimental/laboratory scale testing | wastewater | destruction | effective |  | 75 |
| direct Red 23 | ultraviolet light + carbon nanotubes + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | not effective |  | 83 |
| direct Red 31 | ultraviolet light + carbon nanotubes + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | not effective |  | 83 |
| fluoresein | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | effective | high monetary cost | 77 |
| formic acid | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | somewhat effective | high monetary cost | 77 |
| hexabromocyclododecane | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | somewhat effective | low monetary cost | 61 |
| methyl orange | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | effective | high monetary cost | 77 |
| methylene blue | ultraviolet light + carbon nanotubes + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | somewhat effective |  | 83 |
| methylene orange | ultraviolet light + visible light + carbon nanotubes + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 83 |
| neutral red | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | effective | high monetary cost | 77 |
| nitrobenzene | cerium and hydrogen sulfite-derived reactive species | experimental/laboratory scale testing | wastewater | destruction | not effective | high monetary cost | 74 |
| nitrobenzene | ultraviolet light + carbon nanotubes + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 83 |
| N-Nitrosodimethylamine | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | somewhat effective | low monetary cost | 61 |
| N-Nitrosodimethylamine | membrane bioreactor | commercially available but not in common use | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| nonylphenol | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | effective |  | 75 |
| nonylphenol | constructed wetland | commercially available but not in common use | wastewater | destruction | not effective | high monetary cost | 73 |
| nonylphenol | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | effective | high monetary cost | 77 |
| nonylphenol | ozone | commercially available but not in common use | wastewater | destruction | somewhat effective |  | 75 |
| nonylphenol | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| nonylphenol | ultraviolet light + hydrogen peroxide | experimental/laboratory scale testing | wastewater | destruction | effective |  | 75 |
| octylphenol | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | somewhat effective |  | 75 |
| octylphenol | constructed wetland | commercially available but not in common use | wastewater | destruction | not effective | high monetary cost | 73 |
| octylphenol | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | effective | high monetary cost | 77 |
| octylphenol | ozone | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| octylphenol | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| octylphenol | ultraviolet light + hydrogen peroxide | experimental/laboratory scale testing | wastewater | destruction | effective |  | 75 |
| o-hydroxy atorvastatin | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | somewhat effective |  | 75 |
| o-hydroxy atorvastatin | ozone | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| o-hydroxy atorvastatin | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| o-hydroxy atorvastatin | ultraviolet light + hydrogen peroxide | experimental/laboratory scale testing | wastewater | destruction | effective |  | 75 |
| orange 2 | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | effective | high monetary cost | 77 |
| organophosphorus flame retardants | traditional wastewater treatment | established and in use | wastewater | destruction | somewhat effective | low monetary cost | 55 |
| pentachlorobenzene | constructed wetland | commercially available but not in common use | wastewater | destruction | very effective | high monetary cost | 73 |
| pentafluorobenzoic acid | activated carbon | commercially available but not in common use | groundwater | stop spread of plum | not effective |  | 86 |
| perfluorobutanesulfonic acid | activated carbon | commercially available but not in common use | groundwater | stop spread of plum | somewhat effective |  | 86 |
| perfluorobutanoic acid | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | not effective | low monetary cost | 61 |
| perfluorobutanoic acid | membrane bioreactor | commercially available but not in common use | wastewater | destruction | not effective | medium monetary cost | 61 |
| perfluorohexanesulphonic acid | activated carbon | commercially available but not in common use | groundwater | stop spread of plum | somewhat effective |  | 86 |
| perfluorohexanoic acid | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | not effective | low monetary cost | 61 |
| perfluorohexanoic acid | membrane bioreactor | commercially available but not in common use | wastewater | destruction | not effective | medium monetary cost | 61 |
| perfluorohexanoic acid | activated carbon | commercially available but not in common use | groundwater | stop spread of plum | somewhat effective |  | 86 |
| perfluorooctanesulfonic acid | ultraviolet light + visible light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| perfluorooctanesulfonic acid | ozone | commercially available but not in common use | wastewater | destruction | very effective |  | 78 |
| perfluorooctanesulfonic acid | ultraviolet light + visible light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| perfluorooctanesulfonic acid | constructed wetland | commercially available but not in common use | wastewater | destruction | not effective | high monetary cost | 73 |
| perfluorooctanesulfonic acid | electron beam | experimental/laboratory scale testing | wastewater | destruction | effective  note: while PFOS decreases, other PFAS products form from the breakup of PFOS |  | 87 |
| perfluorooctanesulfonic acid | electron beam + hydrogen peroxide | experimental/laboratory scale testing | wastewater | destruction | effective  note: while PFOS decreases, other PFAS products form from the breakup of PFOS |  | 87 |
| perfluorooctanesulfonic acid | electron beam + sodium persulfate | experimental/laboratory scale testing | wastewater | destruction | effective  note: while PFOS decreases, other PFAS products form from the breakup of PFOS |  | 87 |
| perfluorooctanesulfonic acid | activated carbon | commercially available but not in common use | groundwater | stop spread of plum | effective |  | 86 |
| perfluorooctanoic acid | activated carbon | commercially available but not in common use | groundwater | stop spread of plum | somewhat effective |  | 86 |
| perfluoropentanoic acid | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | not effective | low monetary cost | 61 |
| perfluoropentanoic acid | membrane Bioreactor | commercially available but not in common use | wastewater | destruction | not effective | medium monetary cost | 61 |
| PFAS | activated carbon | commercially available but not in common use | drinking water, wastewater, landfill leachate, groundwater | stop spread of plum | effective | medium monetary cost | 88 |
| PFAS | capping | established and in use | landfill | stop continued contamination | somewhat effective | low monetary cost | 88 |
| PFAS | incineration | established and in use | soil | destruction | very effective | high monetary cost | 88 |
| PFAS | in place thermal | field/pilot scale testing | soil | destruction | effective | high monetary cost | 88 |
| PFAS | ion exchange | established and in use | drinking water, wastewater, landfill leachate, groundwater | stop spread of plum | effective | medium monetary cost | 88 |
| PFAS | nanofiltration | field/pilot scale testing | wastewater, drinking water, landfill leachate | stop continued contamination | somewhat effective | high monetary cost | 88 |
| PFAS | precipitation + flocculation + coagulation | experimental/laboratory scale testing | drinking water, surface water, wastewater | stop continued contamination | effective | low monetary cost | 88 |
| PFAS | redox manipulation | experimental/laboratory scale testing | wastewater, drinking water, surface water, groundwater, soil, landfill leachate, landfill | destruction, stop spread of plum | effective | medium monetary cost | 88 |
| PFAS | reverse osmosis | commercially available but not in common use | wastewater, drinking water, landfill leachate | stop continued contamination | effective | high monetary cost | 88 |
| phenol | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | effective | high monetary cost | 77 |
| Phenol | ultraviolet light + carbon nanotube + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 83 |
| Phenol | ultraviolet light + visible light + carbon nanotube + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 83 |
| Phenol | visible light + carbon nanotube + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | not effective to very effective depending on the type and structure of the carbon nanotube |  | 83 |
| p-hydroxy atorvastatin | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | somewhat effective |  | 75 |
| p-hydroxy atorvastatin | ozone | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| p-hydroxy atorvastatin | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| p-hydroxy atorvastatin | ultraviolet light + hydrogen peroxide | established and in use | wastewater | destruction | effective |  | 75 |
| polycyclic aromatic hydrocarbons | traditional wastewater treatment | established and in use | wastewater | destruction | somewhat effective | low monetary cost | 55 |
| procion red MX-5B | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | effective | high monetary cost | 77 |
| quinoline | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | effective | high monetary cost | 77 |
| reactive black 5 | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | effective | high monetary cost | 77 |
| red acid G | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | effective | high monetary cost | 77 |
| red basic dye | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | effective | high monetary cost | 77 |
| rhodamine 6G | cerium and hydrogen sulfite-derived reactive species | experimental/laboratory scale testing | wastewater | destruction | effective | high monetary cost | 74 |
| rhodamine 6G | ultraviolet light + carbon nanotubes + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | effective |  | 83 |
| rhodamine B | cerium and hydrogen sulfite-derived reactive species | experimental/laboratory scale testing | wastewater | destruction | effective | high monetary cost | 74 |
| rhodamine B | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | effective | high monetary cost | 77 |
| Rhodamine B | ultraviolet light + carbon nanotube + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 83 |
| tetrabromobisphenol A | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | somewhat effective | low monetary cost | 61 |
| tetrabromobisphenol A | membrane bioreactor | commercially available but not in common use | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| thymol blue | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | effective | high monetary cost | 77 |
| trichloromethane | constructed wetland | commercially available but not in common use | wastewater | destruction | not effective | high monetary cost | 73 |
| trifluralin | constructed wetland | commercially available but not in common use | wastewater | destruction | not effective | high monetary cost | 73 |
| tris(2-chloroethyl)phosphate | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | not effective | low monetary cost | 61 |
| tris(2-chloroethyl)phosphate | membrane bioreactor | commercially available but not in common use | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| tris(2-chloroethyl)phosphate | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | effective |  | 75 |
| tris(2-chloroethyl)phosphate | biofilter (anthracite, sand, activated carbon) | experimental/laboratory scale testing | wastewater | stop continued contamination | not effective |  | 76 |
| tris(2-chloroethyl)phosphate | ozone | commercially available but not in common use | wastewater | destruction | somewhat effective |  | 75 |
| tris(2-chloroethyl)phosphate | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| tris(2-chloroethyl)phosphate | ultraviolet light + hydrogen peroxide | experimental/laboratory scale testing | wastewater | destruction | somewhat effective |  | 75 |
| tris(2-chloroisopropyl)phosphate | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | somewhat effective |  | 75 |
| tris(2-chloroisopropyl)phosphate | ozone | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| tris(2-chloroisopropyl)phosphate | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| tris(2-chloroisopropyl)phosphate | ultraviolet light + hydrogen peroxide | experimental/laboratory scale testing | wastewater | destruction | effective |  | 75 |

Table : CEC Treatment Methods: Microplastics.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Contaminant | Technique | Technology Status | Media | Purpose | Effectiveness | References |
| microplastics | traditional wastewater treatment | established and in use | wastewater | stop continued contamination | somewhat effective | 89 |

Table : CEC Treatment Methods: Pharmaceuticals and Personal Care Products.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Contaminant | Technique | Technology Status | Media | Purpose | Effectiveness | Relative Cost | References |
| 17α-ethynylestradiol | ozone | commercially available but not in common use | wastewater | destruction | not effective to very effective depending on application | medium monetary cost | 78,81,90 |
| 17α-ethynylestradiol | hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| 17α-ethynylestradiol | ultraviolet light | commercially available but not in common use | wastewater | destruction | effective |  | 81 |
| 17α-ethynylestradiol | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | somewhat effective to effective |  | 78,81 |
| 17α-ethynylestradiol | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | somewhat effective |  | 81 |
| 17α-ethynylestradiol | ultraviolet light + ozone | commercially available but not in common use | wastewater | destruction | effective |  | 81 |
| 17α-ethynylestradiol | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| 17α-ethynylestradiol | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | somewhat effective | low monetary cost | 61 |
| 17α-ethynylestradiol | membrane bioreactor | commercially available but not in common use | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| 17α-ethynylestradiol | constructed wetland | commercially available but not in common use | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| 17α-ethynylestradiol | moving bed biofilm reactor | experimental/laboratory scale testing | wastewater | destruction | effective | high monetary cost | 61 |
| 17β-estradiol | ozone | commercially available but not in common use | wastewater | destruction | not effective to very effective depending on application | medium monetary cost | 78,81,90 |
| 17β-estradiol | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | effective | low monetary cost | 61 |
| 17β-estradiol | membrane bioreactor | commercially available but not in common use | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| 17β-estradiol | constructed wetland | commercially available but not in common use | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| 17β-estradiol | moving bed biofilm reactor | experimental/laboratory scale testing | wastewater | destruction | effective | high monetary cost | 61 |
| 17β-estradiol | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| 17β-estradiol | ultraviolet light + titanium oxide | commercially available but not in common use | wastewater | destruction | effective to very effective |  | 78,81 |
| 17β-estradiol | hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| 17β-estradiol | ultraviolet light | commercially available but not in common use | wastewater | destruction | effective |  | 81 |
| 17β-estradiol | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | somewhat effective |  | 81 |
| 17β-estradiol | ultraviolet light + ozone | commercially available but not in common use | wastewater | destruction | effective |  | 81 |
| 2-Ethylhexyl ethoxycinnamate | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | somewhat effective | low monetary cost | 61 |
| acetaminophen | ozone | commercially available but not in common use | wastewater | destruction | very effective |  | 75 |
| acetaminophen | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| acetaminophen | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| acetaminophen | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | effective |  | 75 |
| acetaminophen | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | effective |  | 91 |
| acetaminophen | hybrid bioreactor | experimental/laboratory scale testing | wastewater | destruction | effective |  | 51 |
| amoxicillin | ultraviolet light + visible light | commercially available but not in common use | wastewater | destruction | not effective |  | 78 |
| amoxicillin | ozone | commercially available but not in common use | wastewater | destruction | very effective |  | 78 |
| amoxicillin | ultraviolet light + ozone | commercially available but not in common use | wastewater | destruction | very effective |  | 78 |
| amoxicillin | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective  note: took double the time to reduce to zero vs. other very effective treatments |  | 78 |
| amoxicillin | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| amoxicillin | ultrafiltration + activated carbon adsorption + ultrasound irradiation | experimental/laboratory scale testing | wastewater | stop continued contamination | very effective |  | 92 |
| amoxicillin | ultrafiltration | commercially available but not in common use | wastewater | stop continued contamination | not effective |  | 92 |
| amoxicillin | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 92 |
| ampicillin | ultraviolet light | commercially available but not in common use | wastewater | destruction | not effective |  | 93 |
| ampicillin | ultraviolet light + persulfate | experimental/laboratory scale testing | wastewater | destruction | somewhat effective |  | 93 |
| ampicillin | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective |  | 93 |
| androstenedione | ozone | commercially available but not in common use | wastewater | destruction | very effective |  | 62,94 |
| atenolol | biofilter (anthracite, sand, activated carbon) | experimental/laboratory scale testing | wastewater | stop continued contamination | not effective |  | 76 |
| atenolol | ozone | commercially available but not in common use | wastewater | destruction | somewhat effective |  | 75 |
| atenolol | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| atenolol | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| atenolol | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| atenolol | hybrid bioreactor | experimental/laboratory scale testing | wastewater | destruction | effective |  | 51 |
| atenolol | electrodialysis | experimental/laboratory scale testing | wastewater | stop continued contamination | very effective |  | 95 |
| atorvastatin | ozone | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| atorvastatin | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | somewhat effective |  | 75 |
| atorvastatin | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| atorvastatin | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| azithromycin | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | not effective | low monetary cost | 61 |
| azithromycin | membrane bioreactor | commercially available but not in common use | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| azithromycin | moving bed biofilm reactor | experimental/laboratory scale testing | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| azithromycin | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| azithromycin | ozone | commercially available but not in common use | wastewater | destruction | very effective |  | 78 |
| azithromycin | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| benzocaine | hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| benzocaine | ozone | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| benzocaine | ultraviolet light | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| benzocaine | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | not effective |  | 81 |
| benzocaine | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| benzocaine | ultraviolet light + ozone | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| benzophenone | ozone | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| benzophenone | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | somewhat effective |  | 75 |
| benzophenone | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| benzophenone | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| benzotriazole | ozone | commercially available but not in common use | wastewater | destruction | somewhat effective | medium monetary cost | 90 |
| bezafibrate | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | stop continued contamination, destruction | very effective |  | 96 |
| bezafibrate | hybrid bioreactor | experimental/laboratory scale testing | wastewater | destruction | effective |  | 51 |
| bezafibrate | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| bezafibrate | ozone | commercially available but not in common use | wastewater | destruction | very effective |  | 78 |
| bezafibrate | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| caffeine | cerium and hydrogen sulfite-derived reactive species | experimental/laboratory scale testing | wastewater | destruction | not effective | high monetary cost | 74 |
| caffeine | compost-derived bio-based substances with electrical potential | experimental/laboratory scale testing | wastewater | destruction | not effective |  | 97 |
| caffeine | ultraviolet light | commercially available but not in common use | wastewater | destruction | not effective |  | 81,97 |
| caffeine | hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective |  | 81,97 |
| caffeine | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective to somewhat effective |  | 81,97 |
| caffeine | ultraviolet light + hydrogen peroxide + MH0.2 | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 97 |
| caffeine | hydrogen peroxide + MH0.2 | experimental/laboratory scale testing | wastewater | destruction | not effective |  | 97 |
| caffeine | hybrid bioreactor | experimental/laboratory scale testing | wastewater | destruction | effective |  | 51 |
| caffeine | electrodialysis | experimental/laboratory scale testing | wastewater | stop continued contamination | very effective |  | 95 |
| caffeine | ozone | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| caffeine | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | not effective |  | 81 |
| caffeine | ultraviolet light + ozone | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| carbamazepine | ozone | commercially available but not in common use | wastewater | destruction | not effective to very effective depending on the application | medium monetary cost | 75,78,81,90,94 |
| carbamazepine | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | stop continued contamination, destruction | not effective | low monetary cost | 61,96 |
| carbamazepine | membrane bioreactor | commercially available but not in common use | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| carbamazepine | constructed wetland | commercially available but not in common use | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| carbamazepine | moving bed biofilm reactor | experimental/laboratory scale testing | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| carbamazepine | peracetic acid and sunlight | experimental/laboratory scale testing | wastewater | destruction | somewhat effective | high monetary cost | 71 |
| carbamazepine | cerium and hydrogen sulfite-derived reactive species | experimental/laboratory scale testing | wastewater | destruction | somewhat effective | high monetary cost | 74 |
| carbamazepine | biofilter (anthracite, sand, activated carbon) | experimental/laboratory scale testing | wastewater | stop continued contamination | not effective |  | 76 |
| carbamazepine | ultraviolet light + chloramine | experimental/laboratory scale testing | wastewater | destruction | somewhat effective |  | 98 |
| carbamazepine | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | somewhat effective |  | 75 |
| carbamazepine | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective to somewhat effective |  | 75,81 |
| carbamazepine | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| carbamazepine | hybrid bioreactor | experimental/laboratory scale testing | wastewater | destruction | effective |  | 51 |
| carbamazepine | hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective |  | 79,81,99 |
| carbamazepine | hydrogen peroxide + iron + pH7-9 | experimental/laboratory scale testing | wastewater | destruction | not effective |  | 99 |
| carbamazepine | hydrogen peroxide + iron + pH3-5 | experimental/laboratory scale testing | wastewater | destruction | effective |  | 99 |
| carbamazepine | hydrogen peroxide + iron + methanol | experimental/laboratory scale testing | wastewater | destruction | effective |  | 99 |
| carbamazepine | hydrogen peroxide + iron + ultrasonication | experimental/laboratory scale testing | wastewater | destruction | not effective |  | 99 |
| carbamazepine | hydrogen peroxide + acid washed iron + ultrasonication | experimental/laboratory scale testing | wastewater | destruction | effective |  | 99 |
| carbamazepine | hydrogen peroxide + iron oxide + ultrasonication | experimental/laboratory scale testing | wastewater | destruction | not effective |  | 99 |
| carbamazepine | hydrogen peroxide + iron oxide + ultrasonication | experimental/laboratory scale testing | wastewater | destruction | not effective |  | 99 |
| carbamazepine | carbon nanotubes + aluminum oxide (1:1) | experimental/laboratory scale testing | wastewater | stop continued contamination | effective |  | 100 |
| carbamazepine | carbon nanotubes | experimental/laboratory scale testing | wastewater | stop continued contamination | somewhat effective |  | 100 |
| carbamazepine | aluminum oxide | experimental/laboratory scale testing | wastewater | stop continued contamination | not effective |  | 100 |
| carbamazepine | ultrafiltration + activated carbon adsorption + ultrasound irradiation | experimental/laboratory scale testing | wastewater | stop continued contamination | very effective |  | 92 |
| carbamazepine | ultrafiltration | commercially available but not in common use | wastewater | stop continued contamination | not effective |  | 92 |
| carbamazepine | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 92 |
| Carbamazepine | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| Carbamazepine | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| Carbamazepine | ultraviolet light + carbon nanotubes + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 83 |
| carbamazepine | electrodialysis | experimental/laboratory scale testing | wastewater | stop continued contamination | very effective |  | 95 |
| carbamazepine | chlorine | established and in use | wastewater | destruction | not effective |  | 79 |
| carbamazepine | ultraviolet light + free chlorine | commercially available but not in common use | wastewater | destruction | effective |  | 79 |
| carbamazepine | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | effective |  | 79 |
| carbamazepine | ultraviolet light | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| carbamazepine | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | not effective |  | 81 |
| carbamazepine | ultraviolet light + ozone | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| cephalothin | ultraviolet light | commercially available but not in common use | wastewater | destruction | somewhat effective |  | 93 |
| cephalothin | ultraviolet light + persulfate | experimental/laboratory scale testing | wastewater | destruction | somewhat effective |  | 93 |
| cephalothin | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective |  | 93 |
| ciprofloxacin | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | somewhat effective | low monetary cost | 61 |
| ciprofloxacin | membrane bioreactor | commercially available but not in common use | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| ciprofloxacin | moving bed biofilm reactor | experimental/laboratory scale testing | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| ciprofloxacin | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | stop continued contamination, destruction | very effective |  | 96 |
| ciprofloxacin | hybrid bioreactor | experimental/laboratory scale testing | wastewater | destruction | effective |  | 51 |
| citalopram | ozone | commercially available but not in common use | wastewater | destruction | effective to very effective | medium monetary cost | 78,90 |
| citalopram | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| citalopram | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| clarithromycin | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | somewhat effective | low monetary cost | 61 |
| clarithromycin | membrane bioreactor | commercially available but not in common use | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| clarithromycin | constructed wetland | commercially available but not in common use | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| clarithromycin | moving bed biofilm reactor | experimental/laboratory scale testing | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| clarithromycin | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| clarithromycin | ozone | commercially available but not in common use | wastewater | destruction | very effective |  | 78 |
| clarithromycin | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| clopidogrel | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| clopidogrel | ozone | commercially available but not in common use | wastewater | destruction | very effective |  | 78 |
| clopidogrel | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| cocktail of five commonly used pharmaceuticals, carbamazepine, diclofenac, gabapentin, oxazepame, and fluconazole | magnetoelectric nanocatalysts + cobalt (II) ferrite | experimental/laboratory scale testing | wastewater | stop continued contamination | not effective |  | 101 |
| cocktail of five commonly used pharmaceuticals, carbamazepine, diclofenac, gabapentin, oxazepame, and fluconazole | magnetoelectric nanocatalysts + bismuth ferrite | experimental/laboratory scale testing | wastewater | stop continued contamination | not effective |  | 101 |
| cocktail of five commonly used pharmaceuticals, carbamazepine, diclofenac, gabapentin, oxazepame, and fluconazole | magnetoelectric nanocatalysts + magnetostrictive cobalt (II) ferrite cores coated with multiferroic bismuth (III) ferrite shells | experimental/laboratory scale testing | wastewater | stop continued contamination | effective |  | 101 |
| DEET | traditional wastewater treatment | established and in use | wastewater | destruction | somewhat effective | low monetary cost | 55 |
| diclofenac | ozone | commercially available but not in common use | wastewater | destruction | not effective to very effective depending on application | medium monetary cost | 75,78,81,90,94,102,102 |
| diclofenac | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | not effective | low monetary cost | 61 |
| diclofenac | membrane bioreactor | commercially available but not in common use | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| diclofenac | constructed wetland | commercially available but not in common use | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| diclofenac | moving bed biofilm reactor | experimental/laboratory scale testing | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| diclofenac | peracetic acid and sunlight | experimental/laboratory scale testing | wastewater | destruction | effective | high monetary cost | 71 |
| diclofenac | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | effective |  | 75 |
| diclofenac | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective to very effective depending on application |  | 75,81,103 |
| diclofenac | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| diclofenac | molecularly imprinted polymer | experimental/laboratory scale testing | wastewater | stop continued contamination | somewhat effective |  | 104 |
| diclofenac | carbon nanotubes + aluminum oxide (1:1) | experimental/laboratory scale testing | wastewater | stop continued contamination | somewhat effective |  | 100 |
| diclofenac | carbon nanotubes | experimental/laboratory scale testing | wastewater | stop continued contamination | somewhat effective |  | 100 |
| diclofenac | aluminum oxide | experimental/laboratory scale testing | wastewater | stop continued contamination | not effective |  | 100 |
| diclofenac | ultrasonication | experimental/laboratory scale testing | wastewater | destruction | somewhat effective |  | 102 |
| diclofenac | ultrasonication + ozone | experimental/laboratory scale testing | wastewater | destruction | effective |  | 102 |
| diclofenac | ultrafiltration + activated carbon adsorption + ultrasound irradiation | experimental/laboratory scale testing | wastewater | stop continued contamination | very effective |  | 92 |
| diclofenac | ultrafiltration | commercially available but not in common use | wastewater | stop continued contamination | not effective |  | 92 |
| diclofenac | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 92 |
| diclofenac | ultraviolet light | commercially available but not in common use | wastewater | destruction | not effective to very effective depending on application  note: took double the time to reduce to zero vs. other very effective treatments |  | 78,81 |
| diclofenac | ultraviolet light + ozone | commercially available but not in common use | wastewater | destruction | not effective to very effective depending on application |  | 78,81 |
| diclofenac | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | not effective to very effective depending on application  note: took double the time to reduce to zero vs. other very effective treatments |  | 78,81 |
| diclofenac | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| diclofenac | electrodialysis | experimental/laboratory scale testing | wastewater | stop continued contamination | very effective |  | 95 |
| diclofenac | chlorine | established and in use | wastewater | destruction | not effective |  | 79 |
| diclofenac | hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective |  | 79,81 |
| diclofenac | ultraviolet light + free chlorine | commercially available but not in common use | wastewater | destruction | effective |  | 79 |
| diclofenac | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | effective |  | 79 |
| diclofenac | sonolysis | experimental/laboratory scale testing | wastewater | destruction | not effective |  | 105 |
| diclofenac | photocatalysis | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 105 |
| diclofenac | sonophotocatalysis | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 105 |
| dilantin | ozone | commercially available but not in common use | wastewater | destruction | somewhat effective |  | 75 |
| dilantin | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | not effective |  | 75 |
| dilantin | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| dilantin | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| dimethyl phthalate | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | somewhat effective | high monetary cost | 77 |
| dioxbenzone | hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| dioxbenzone | ozone | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| dioxbenzone | ultraviolet light | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| dioxbenzone | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | somewhat effective |  | 81 |
| dioxbenzone | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| dioxbenzone | ultraviolet light + ozone | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| diphenhydramine | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| diphenhydramine | ozone | commercially available but not in common use | wastewater | destruction | very effective |  | 78 |
| diphenhydramine | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| enrofloxacin | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | not effective | low monetary cost | 61 |
| enrofloxacin | membrane bioreactor | commercially available but not in common use | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| enrofloxacin | moving bed biofilm reactor | experimental/laboratory scale testing | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| erythromycin | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | not effective | low monetary cost | 61 |
| erythromycin | membrane bioreactor | commercially available but not in common use | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| erythromycin | constructed wetland | commercially available but not in common use | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| erythromycin | moving bed biofilm reactor | experimental/laboratory scale testing | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| erythromycin | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| erythromycin | ozone | commercially available but not in common use | wastewater | destruction | very effective |  | 78 |
| erythromycin | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | somewhat effective |  | 78 |
| estradiol | ozone | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| estradiol | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | somewhat effective |  | 75 |
| estradiol | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| estradiol | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| estrone | ozone | commercially available but not in common use | wastewater | destruction | effective to very effective | medium monetary cost | 75,78,90,94 |
| estrone | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | somewhat effective | low monetary cost | 61 |
| estrone | membrane bioreactor | commercially available but not in common use | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| estrone | constructed wetland | commercially available but not in common use | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| estrone | moving bed biofilm reactor | experimental/laboratory scale testing | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| estrone | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | somewhat effective |  | 75 |
| estrone | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| estrone | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| estrone | ultraviolet light + zinc oxide | experimental/laboratory scale testing | wastewater | destruction | effective |  | 106 |
| estrone | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | somewhat effective to effective |  | 78,106 |
| estrone | direct photolysis | experimental/laboratory scale testing | wastewater | destruction | not effective |  | 106 |
| estrone | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| fenofibrate | hybrid bioreactor | experimental/laboratory scale testing | wastewater | destruction | effective |  | 51 |
| fluoxetine | biofilter (anthracite, sand, activated carbon) | experimental/laboratory scale testing | wastewater | stop continued contamination | not effective |  | 76 |
| fluoxetine | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| fluoxetine | ozone | commercially available but not in common use | wastewater | destruction | very effective |  | 78 |
| fluoxetine | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| fragrances | traditional wastewater treatment | established and in use | wastewater | destruction | somewhat effective | low monetary cost | 55 |
| furosemide | electrodialysis | experimental/laboratory scale testing | wastewater | stop continued contamination | very effective |  | 95 |
| galaxolide | microalgae mono-digestion | experimental/laboratory scale testing | wastewater | destruction | somewhat effective | medium monetary cost | 107 |
| galaxolide | ozone | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| galaxolide | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | somewhat effective |  | 75 |
| galaxolide | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective |  | 75 |
| galaxolide | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| gemfibrozil | ozone | commercially available but not in common use | wastewater | destruction | somewhat effective to very effective depending on application | medium monetary cost | 75,90 |
| gemfibrozil | biofilter (anthracite, sand, activated carbon) | experimental/laboratory scale testing | wastewater | stop continued contamination | not effective |  | 76 |
| gemfibrozil | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | effective |  | 75 |
| gemfibrozil | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| gemfibrozil | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| gentian violet | cerium and hydrogen sulfite-derived reactive species | experimental/laboratory scale testing | wastewater | destruction | effective | high monetary cost | 74 |
| hydrochlorothiazide | photoelectrochemical + cadmium selenium quantum dots + tin oxide nanotubes nanotubes | experimental/laboratory scale testing | wastewater | destruction | effective |  | 108 |
| hydrochlorothiazide | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| hydrochlorothiazide | ozone | commercially available but not in common use | wastewater | destruction | very effective |  | 78 |
| hydrochlorothiazide | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| hydrochlorothiazide | electrodialysis | experimental/laboratory scale testing | wastewater | stop continued contamination | very effective |  | 95 |
| hydrocodone | ozone | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| hydrocodone | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | somewhat effective |  | 75 |
| hydrocodone | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| hydrocodone | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| ibuprofen | ozone | commercially available but not in common use | wastewater | destruction | not effective to effective | medium monetary cost | 75,78,81,90 |
| ibuprofen | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | somewhat effective | high monetary cost | 77 |
| ibuprofen | titanium oxide nanofibers combined with boron nitride nanosheets | experimental/laboratory scale testing | wastewater | destruction | somewhat effective | high monetary cost | 109 |
| ibuprofen | titanium oxide nanofibers combined with boron nitride nanosheets under ultraviolet light | experimental/laboratory scale testing | wastewater | destruction | effective | high monetary cost | 109 |
| ibuprofen | flat sheet dual membrane electrode (2 or greater voltage) | experimental/laboratory scale testing | wastewater | destruction | effective | high monetary cost | 110 |
| ibuprofen | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | not effective |  | 75 |
| ibuprofen | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective to very effective depending on application |  | 75,81 |
| ibuprofen | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| ibuprofen | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | stop continued contamination, destruction | very effective |  | 96 |
| ibuprofen | constructed wetland | commercially available but not in common use | wastewater | stop spread of plum | somewhat effective  note: plants take up the ibuprofen |  | 111 |
| ibuprofen | hybrid bioreactor | experimental/laboratory scale testing | wastewater | destruction | effective |  | 51 |
| ibuprofen | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| ibuprofen | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | not effective to very effective depending on application |  | 78 |
| ibuprofen | electrodialysis | experimental/laboratory scale testing | wastewater | stop continued contamination | very effective |  | 95 |
| ibuprofen | hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| ibuprofen | ultraviolet light | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| ibuprofen | ultraviolet light + ozone | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| ibuprofen | enhanced-photocatalysis | experimental/laboratory scale testing | wastewater | destruction | somewhat effective |  | 112 |
| ibuprofen | sonophotocatalysis | experimental/laboratory scale testing | wastewater | destruction | somewhat effective |  | 112 |
| ibuprofen | photo-Fenton | experimental/laboratory scale testing | wastewater | destruction | somewhat effective |  | 112 |
| ibuprofen | sonophoto-Fenton | experimental/laboratory scale testing | wastewater | destruction | somewhat effective |  | 112 |
| ibuprofen | titanium oxide + iron + sonolysis | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 112 |
| indomethacin | hybrid bioreactor | experimental/laboratory scale testing | wastewater | destruction | effective |  | 51 |
| iopromide | ozone | commercially available but not in common use | wastewater | destruction | somewhat effective |  | 75 |
| iopromide | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | somewhat effective |  | 75 |
| iopromide | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| iopromide | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| isoproturon | ozone | commercially available but not in common use | wastewater | destruction | somewhat effective | medium monetary cost | 90 |
| ketoprofen | photoelectrochemical + tungsten oxide thin film + no electrical potential | experimental/laboratory scale testing | wastewater | destruction | not effective |  | 113 |
| ketoprofen | photoelectrochemical + tungsten oxide thin film + with electrical potential | experimental/laboratory scale testing | wastewater | destruction | somewhat effective |  | 113 |
| ketoprofen | photoelectrochemical + tungsten oxide and beta25 thin film + with electrical potential | experimental/laboratory scale testing | wastewater | destruction | effective |  | 113 |
| ketoprofen | hybrid bioreactor | experimental/laboratory scale testing | wastewater | destruction | effective |  | 51 |
| lamotrigine | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | not effective | low monetary cost | 61 |
| lamotrigine | membrane bioreactor | commercially available but not in common use | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| levofloxacin | photoelectrochemical + tungsten oxide thin film + with electrical potential | experimental/laboratory scale testing | wastewater | destruction | effective |  | 113 |
| levofloxacin | photoelectrochemical + tungsten oxide and beta25 thin film + with electrical potential | experimental/laboratory scale testing | wastewater | destruction | effective |  | 113 |
| levofloxacin | photoelectrochemical + tungsten oxide thin film + no electrical potential | experimental/laboratory scale testing | wastewater | destruction | effective |  | 113 |
| linear alkylbenzene sulfonates | ultrasonication | experimental/laboratory scale testing | wastewater | destruction | somewhat effective |  | 114 |
| mecoprop | ozone | commercially available but not in common use | wastewater | destruction | somewhat effective | medium monetary cost | 90 |
| mefenamic acid | hybrid bioreactor | experimental/laboratory scale testing | wastewater | destruction | effective |  | 51 |
| meprobamate | ozone | commercially available but not in common use | wastewater | destruction | somewhat effective |  | 75 |
| meprobamate | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | not effective |  | 75 |
| meprobamate | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| meprobamate | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| mestranol | hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| mestranol | ozone | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| mestranol | ultraviolet light | commercially available but not in common use | wastewater | destruction | effective |  | 81 |
| mestranol | ultraviolet light + titanium oxide | commercially available but not in common use | wastewater | destruction | very effective |  | 81 |
| mestranol | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | effective |  | 81 |
| mestranol | ultraviolet light + ozone | commercially available but not in common use | wastewater | destruction | effective |  | 81 |
| metformin | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | effective | low monetary cost | 61 |
| metformin | membrane bioreactor | commercially available but not in common use | wastewater | destruction | effective | medium monetary cost | 61 |
| metformin | constructed wetland | commercially available but not in common use | wastewater | destruction | very effective | high monetary cost | 61 |
| methyl blue | cerium and hydrogen sulfite-derived reactive species | experimental/laboratory scale testing | wastewater | destruction | effective | high monetary cost | 74 |
| methyl dihydrojasmonate | microalgae mono-digestion | experimental/laboratory scale testing | wastewater | destruction | somewhat effective | medium monetary cost | 107 |
| methylene blue | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | effective | high monetary cost | 77 |
| metoprolol | ozone | commercially available but not in common use | wastewater | destruction | somewhat effective to very effective | medium monetary cost | 78,90 |
| metoprolol | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| metoprolol | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| metoprolol | electrodialysis | experimental/laboratory scale testing | wastewater | stop continued contamination | very effective |  | 95 |
| metronidazole | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | stop continued contamination, destruction | somewhat effective |  | 96 |
| metronidazole | visible light + anaerobic conditions | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 115 |
| metronidazole | aerobic conditions | established and in use | wastewater | destruction | somewhat effective |  | 115 |
| metronidazole | visible light + aerobic conditions | experimental/laboratory scale testing | wastewater | destruction | somewhat effective |  | 115 |
| metronidazole | visible light + aerobic conditions + iron | experimental/laboratory scale testing | wastewater | destruction | somewhat effective |  | 115 |
| naproxen | ozone | commercially available but not in common use | wastewater | destruction | somewhat effective to very effective | medium monetary cost | 75,78,90 |
| naproxen | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | somewhat effective | high monetary cost | 77 |
| naproxen | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | not effective |  | 75 |
| naproxen | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | somewhat effective |  | 75 |
| naproxen | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| naproxen | hybrid bioreactor | experimental/laboratory scale testing | wastewater | destruction | effective |  | 51 |
| naproxen | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| naproxen | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| nitrobenzene | ultraviolet light | commercially available but not in common use | wastewater | destruction | not effective |  | 93 |
| nitrobenzene | ultraviolet light + persulfate | experimental/laboratory scale testing | wastewater | destruction | somewhat effective |  | 93 |
| norfloxacin | cerium and hydrogen sulfite-derived reactive species | experimental/laboratory scale testing | wastewater | destruction | somewhat effective | high monetary cost | 74 |
| norfluoxetine | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| norfluoxetine | ozone | commercially available but not in common use | wastewater | destruction | very effective |  | 78 |
| norfluoxetine | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| ofloxacin | hybrid bioreactor | experimental/laboratory scale testing | wastewater | destruction | effective |  | 51 |
| oxybenzone | ozone | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| oxybenzone | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | somewhat effective |  | 75 |
| oxybenzone | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | somewhat effective |  | 75 |
| oxybenzone | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| progesterone | ozone | commercially available but not in common use | wastewater | destruction | not effective to effective depending on application |  | 75,81 |
| progesterone | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | somewhat effective |  | 75 |
| progesterone | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | somewhat effective to effective |  | 75,81 |
| progesterone | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| progesterone | hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| progesterone | ultraviolet light | commercially available but not in common use | wastewater | destruction | effective |  | 81 |
| progesterone | ultraviolet light + titanium oxide | commercially available but not in common use | wastewater | destruction | somewhat effective |  | 81 |
| progesterone | ultraviolet light + ozone | commercially available but not in common use | wastewater | destruction | effective |  | 81 |
| propranolol | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| propranolol | ozone | commercially available but not in common use | wastewater | destruction | very effective |  | 78 |
| propranolol | ultraviolet light + titanium oxide | commercially available but not in common use | wastewater | destruction | very effective |  | 78 |
| propyl paraben | activated persulfate using iron-containing magnetic carbon xerogels | experimental/laboratory scale testing | wastewater | stop continued contamination | somewhat effective |  | 116 |
| sucrose | magnetic nanophotocatalysts | experimental/laboratory scale testing | drinking water | destruction | effective | high monetary cost | 77 |
| sulfamethoxazole | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | somewhat effective | low monetary cost | 61,96 |
| sulfamethoxazole | membrane bioreactor | commercially available but not in common use | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| sulfamethoxazole | constructed wetland | commercially available but not in common use | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| sulfamethoxazole | moving bed biofilm reactor | experimental/laboratory scale testing | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| sulfamethoxazole | peracetic acid and sunlight | experimental/laboratory scale testing | wastewater | destruction | somewhat effective | high monetary cost | 71 |
| sulfamethoxazole | cerium and hydrogen sulfite-derived reactive species | experimental/laboratory scale testing | wastewater | destruction | somewhat effective | high monetary cost | 74 |
| sulfamethoxazole | biofilter (anthracite, sand, activated carbon) | experimental/laboratory scale testing | wastewater | stop continued contamination | somewhat effective |  | 76 |
| sulfamethoxazole | ozone | commercially available but not in common use | wastewater | destruction | effective to very effective | medium monetary cost | 75,78,90,117 |
| sulfamethoxazole | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | somewhat effective |  | 75 |
| sulfamethoxazole | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| sulfamethoxazole | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| sulfamethoxazole | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| sulfamethoxazole | ultraviolet light + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| sulfamethoxazole | ultrasonication | commercially available but not in common use | wastewater | destruction | not effective |  | 117 |
| sulfamethoxazole | ultrasonication + ozone | experimental/laboratory scale testing | wastewater | destruction | effective |  | 117 |
| sulfamethoxazole | chlorine | established and in use | wastewater | destruction | not effective |  | 79 |
| sulfamethoxazole | hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective |  | 79 |
| sulfamethoxazole | ultraviolet light + free chlorine | commercially available but not in common use | wastewater | destruction | effective |  | 79 |
| sulfamethoxazole | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | effective |  | 79 |
| sunscreen | traditional wastewater treatment | established and in use | wastewater | destruction | very effective | low monetary cost | 55 |
| testosterone | ozone | commercially available but not in common use | wastewater | destruction | effective to very effective |  | 75,118 |
| testosterone | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | somewhat effective |  | 75 |
| testosterone | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| testosterone | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| tetracycline | geofilter (sand and stevensite) | experimental/laboratory scale testing | wastewater | stop continued contamination | effective |  | 119 |
| tetracycline | aerobic granular sludge | experimental/laboratory scale testing | wastewater | destruction | effective |  | 120 |
| tonalide | microalgae mono-digestion | experimental/laboratory scale testing | wastewater | destruction | somewhat effective | medium monetary cost | 107 |
| tramadol | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| tramadol | ozone | commercially available but not in common use | wastewater | destruction | very effective |  | 78 |
| tramadol | ultraviolet light + titanium oxide | commercially available but not in common use | wastewater | destruction | very effective |  | 78 |
| triclosan | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | somewhat effective | low monetary cost | 61 |
| triclosan | membrane bioreactor | commercially available but not in common use | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| triclosan | constructed wetland | commercially available but not in common use | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| triclosan | moving bed biofilm reactor | experimental/laboratory scale testing | wastewater | destruction | effective | high monetary cost | 61 |
| triclosan | microalgae mono-digestion | experimental/laboratory scale testing | wastewater | destruction | somewhat effective | medium monetary cost | 107 |
| triclosan | traditional wastewater treatment | established and in use | wastewater | destruction | somewhat effective | low monetary cost | 55 |
| triclosan | ozone | commercially available but not in common use | wastewater | destruction | not effective to very effective depending on application |  | 75,81,94 |
| triclosan | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | somewhat effective |  | 75 |
| triclosan | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | somewhat effective to very effective |  | 75,81,103 |
| triclosan | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| triclosan | hydrogen peroxide | commercially available but not in common use | wastewater | destruction | not effective |  | 81 |
| triclosan | ultraviolet light | commercially available but not in common use | wastewater | destruction | effective |  | 103 |
| triclosan | ultraviolet light + titanium oxide | commercially available but not in common use | wastewater | destruction | somewhat effective |  | 81 |
| triclosan | ultraviolet light + ozone | commercially available but not in common use | wastewater | destruction | very effective |  | 81 |
| trimethoprim | ozone | commercially available but not in common use | wastewater | destruction | very effective | medium monetary cost | 75,78,90 |
| trimethoprim | conventional activated sludge at wastewater treatment plant | established and in use | wastewater | destruction | somewhat effective | low monetary cost | 61 |
| trimethoprim | membrane bioreactor | commercially available but not in common use | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| trimethoprim | constructed wetland | commercially available but not in common use | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| trimethoprim | moving bed biofilm reactor | experimental/laboratory scale testing | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| trimethoprim | activated carbon | commercially available but not in common use | wastewater | stop continued contamination | effective |  | 75 |
| trimethoprim | ultraviolet light + hydrogen peroxide | commercially available but not in common use | wastewater | destruction | effective |  | 75 |
| trimethoprim | reverse osmosis | commercially available but not in common use | wastewater | stop continued contamination | very effective |  | 75 |
| trimethoprim | hybrid bioreactor | experimental/laboratory scale testing | wastewater | destruction | effective |  | 51 |
| trimethoprim | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| trimethoprim | ultraviolet light + titanium oxide | commercially available but not in common use | wastewater | destruction | very effective |  | 78 |
| trimethoprim | electrodialysis | experimental/laboratory scale testing | wastewater | stop continued contamination | very effective |  | 95 |
| venlafaxine | ultraviolet light + ozone + titanium oxide | experimental/laboratory scale testing | wastewater | destruction | very effective |  | 78 |
| venlafaxine | ultraviolet light + titanium oxide | commercially available but not in common use | wastewater | destruction | very effective |  | 78 |
| venlafaxine | ozone | commercially available but not in common use | wastewater | destruction | somewhat effective to very effective depending on application | medium monetary cost | 78,90 |

Table : Treatment Techniques for PFAS.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Treatment type | Status | Media | Purpose | Effectiveness | Relative Cost | References |
| capping | In use | landfill | stop continued contamination | somewhat effective | low monetary cost | 88 |
| incineration | In use | soil | destruction | very effective | high monetary cost | 88 |
| ion exchange | In use | drinking water, wastewater, landfill leachate, groundwater | stop spread of plum | effective | medium monetary cost | 88 |
| in place thermal | field/pilot scale testing | soil | destruction | effective | high monetary cost | 88 |
| nanofiltration | field/pilot scale testing | wastewater, drinking water, landfill leachate | stop continued contamination | somewhat effective | high monetary cost | 88 |
| electron beam | experimental/laboratory scale | wastewater | destruction | effective  note: while PFOS decreases, other PFAS products form from the breakup of PFOS |  | 87 |
| electron beam + hydrogen peroxide | experimental/laboratory scale | wastewater | destruction | effective  note: while PFOS decreases, other PFAS products form from the breakup of PFOS |  | 87 |
| electron beam + sodium persulfate | experimental/laboratory scale | wastewater | destruction | effective  note: while PFOS decreases, other PFAS products form from the breakup of PFOS |  | 87 |

Table : Established and In Use Technologies for Wastewater Treatment.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Contaminant | Treatment Technique | Media | Purpose | Effectiveness | References |
| metronidazole | aerobic conditions | wastewater | destruction | somewhat effective | 115 |
| imidacloprid | chlorine | wastewater | destruction | not effective | 79 |
| carbamazepine | chlorine | wastewater | destruction | not effective | 79 |
| diclofenac | chlorine | wastewater | destruction | not effective | 79 |
| sulfamethoxazole | chlorine | wastewater | destruction | not effective | 79 |
| acetamiprid | conventional activated sludge | wastewater | destruction | not effective | 61 |
| clothianidin | conventional activated sludge | wastewater | destruction | not effective | 61 |
| imidacloprid | conventional activated sludge | wastewater | destruction | not effective | 61 |
| 2,6-Ditert-butyl-4-methylphenol | conventional activated sludge | wastewater | destruction | effective | 61 |
| benzotriazole | conventional activated sludge | wastewater | destruction | somewhat effective | 61 |
| hexabromocyclododecane | conventional activated sludge | wastewater | destruction | somewhat effective | 61 |
| N-Nitrosodimethylamine | conventional activated sludge | wastewater | destruction | somewhat effective | 61 |
| perfluorobutanoic acid | conventional activated sludge | wastewater | destruction | not effective | 61 |
| perfluorohexanoic acid | conventional activated sludge | wastewater | destruction | not effective | 61 |
| perfluoropentanoic acid | conventional activated sludge | wastewater | destruction | not effective | 61 |
| tetrabromobisphenol A | conventional activated sludge | wastewater | destruction | somewhat effective | 61 |
| tris(2-chloroethyl)phosphate | conventional activated sludge | wastewater | destruction | not effective | 61 |
| 17α-ethynylestradiol | conventional activated sludge | wastewater | destruction | somewhat effective | 61 |
| 17β-estradiol | conventional activated sludge | wastewater | destruction | effective | 61 |
| 2-Ethylhexyl ethoxycinnamate | conventional activated sludge | wastewater | destruction | somewhat effective | 61 |
| azithromycin | conventional activated sludge | wastewater | destruction | not effective | 61 |
| bezafibrate | conventional activated sludge | wastewater | stop continued contamination, destruction | very effective | 96 |
| carbamazepine | conventional activated sludge | wastewater | stop continued contamination, destruction | not effective | 61,96 |
| ciprofloxacin | conventional activated sludge | wastewater | destruction | somewhat effective | 61 |
| ciprofloxacin | conventional activated sludge | wastewater | stop continued contamination, destruction | very effective | 96 |
| clarithromycin | conventional activated sludge | wastewater | destruction | somewhat effective | 61 |
| diclofenac | conventional activated sludge | wastewater | destruction | not effective | 61 |
| enrofloxacin | conventional activated sludge | wastewater | destruction | not effective | 61 |
| erythromycin | conventional activated sludge | wastewater | destruction | not effective | 61 |
| estrone | conventional activated sludge | wastewater | destruction | somewhat effective | 61 |
| ibuprofen | conventional activated sludge | wastewater | stop continued contamination, destruction | very effective | 96 |
| lamotrigine | conventional activated sludge | wastewater | destruction | not effective | 61 |
| metformin | conventional activated sludge | wastewater | destruction | effective | 61 |
| metronidazole | conventional activated sludge | wastewater | stop continued contamination, destruction | somewhat effective | 96 |
| sulfamethoxazole | conventional activated sludge | wastewater | destruction | somewhat effective | 61,96 |
| triclosan | conventional activated sludge | wastewater | destruction | somewhat effective | 61 |
| trimethoprim | conventional activated sludge | wastewater | destruction | somewhat effective | 61 |
| organophosphorus flame retardants | whole wastewater treatment plant | wastewater | destruction | somewhat effective | 55 |
| polycyclic aromatic hydrocarbons | whole wastewater treatment plant | wastewater | destruction | somewhat effective | 55 |
| microplastics | whole wastewater treatment plant | wastewater | stop continued contamination | somewhat effective | 89 |
| DEET | whole wastewater treatment plant | wastewater | destruction | somewhat effective | 55 |
| fragrances | whole wastewater treatment plant | wastewater | destruction | somewhat effective | 55 |
| sunscreen | whole wastewater treatment plant | wastewater | destruction | very effective | 55 |
| triclosan | whole wastewater treatment plant | wastewater | destruction | somewhat effective | 55 |

Table : Activated Carbon - Commercially Available, but Not Commonly Used for Wastewater Treatment.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Contaminant | Media | Purpose | Effectiveness | Relative Cost | References |
| atrazine | wastewater | stop continued contamination | very effective |  | 75 |
| N,N-diethyl-meta-toluamide | wastewater | stop continued contamination | not effective |  | 75 |
| bisphenol a | wastewater | stop continued contamination | somewhat effective |  | 75 |
| butylated hydroxyanisole | wastewater | stop continued contamination | somewhat effective |  | 75 |
| butylated hydroxytoluene | wastewater | stop continued contamination | somewhat effective |  | 75 |
| butylbenzyl phthalate | wastewater | stop continued contamination | somewhat effective |  | 75 |
| dioctyl phthalate | wastewater | stop continued contamination | somewhat effective |  | 75 |
| nonylphenol | wastewater | stop continued contamination | effective |  | 75 |
| octylphenol | wastewater | stop continued contamination | somewhat effective |  | 75 |
| o-hydroxy atorvastatin | wastewater | stop continued contamination | somewhat effective |  | 75 |
| pentafluorobenzoic acid | groundwater | stop spread of plum | not effective |  | 86 |
| perfluorobutanesulfonic acid | groundwater | stop spread of plum | somewhat effective |  | 86 |
| perfluorohexanesulphonic acid | groundwater | stop spread of plum | somewhat effective |  | 86 |
| perfluorohexanoic acid | groundwater | stop spread of plum | somewhat effective |  | 86 |
| perfluorooctanesulfonic acid | groundwater | stop spread of plum | effective |  | 86 |
| perfluorooctanoic acid | groundwater | stop spread of plum | somewhat effective |  | 86 |
| PFAS | drinking water, wastewater, landfill leachate, groundwater | stop spread of plum | effective | medium monetary cost | 88 |
| p-hydroxy atorvastatin | wastewater | stop continued contamination | somewhat effective |  | 75 |
| tris(2-chloroethyl)phosphate | wastewater | stop continued contamination | effective |  | 75 |
| tris(2-chloroisopropyl)phosphate | wastewater | stop continued contamination | somewhat effective |  | 75 |
| acetaminophen | wastewater | stop continued contamination | very effective |  | 75 |
| acetaminophen | wastewater | stop continued contamination | effective |  | 91 |
| amoxicillin | wastewater | stop continued contamination | very effective |  | 92 |
| atenolol | wastewater | stop continued contamination | very effective |  | 75 |
| atorvastatin | wastewater | stop continued contamination | somewhat effective |  | 75 |
| benzophenone | wastewater | stop continued contamination | somewhat effective |  | 75 |
| carbamazepine | wastewater | stop continued contamination | somewhat effective |  | 75 |
| carbamazepine | wastewater | stop continued contamination | very effective |  | 92 |
| diclofenac | wastewater | stop continued contamination | effective |  | 75 |
| diclofenac | wastewater | stop continued contamination | very effective |  | 92 |
| dilantin | wastewater | stop continued contamination | not effective |  | 75 |
| estradiol | wastewater | stop continued contamination | somewhat effective |  | 75 |
| estrone | wastewater | stop continued contamination | somewhat effective |  | 75 |
| galaxolide | wastewater | stop continued contamination | somewhat effective |  | 75 |
| gemfibrozil | wastewater | stop continued contamination | effective |  | 75 |
| hydrocodone | wastewater | stop continued contamination | somewhat effective |  | 75 |
| ibuprofen | wastewater | stop continued contamination | not effective |  | 75 |
| iopromide | wastewater | stop continued contamination | somewhat effective |  | 75 |
| meprobamate | wastewater | stop continued contamination | not effective |  | 75 |
| naproxen | wastewater | stop continued contamination | not effective |  | 75 |
| oxybenzone | wastewater | stop continued contamination | somewhat effective |  | 75 |
| progesterone | wastewater | stop continued contamination | somewhat effective |  | 75 |
| sulfamethoxazole | wastewater | stop continued contamination | somewhat effective |  | 75 |
| testosterone | wastewater | stop continued contamination | somewhat effective |  | 75 |
| triclosan | wastewater | stop continued contamination | somewhat effective |  | 75 |
| trimethoprim | wastewater | stop continued contamination | effective |  | 75 |

Table : Constructed Wetland - Commercially Available, but Not Commonly Used for Wastewater Treatment.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Contaminant | Media | Purpose | Effectiveness | Relative Cost | References |
| alachlor | wastewater | destruction | not effective | high monetary cost | 73 |
| atrazine | wastewater | destruction | not effective | high monetary cost | 73 |
| chlorpyrifos | wastewater | destruction | somewhat effective | high monetary cost | 73 |
| diuron | wastewater | destruction | not effective | high monetary cost | 73 |
| endosulfan | wastewater | destruction | somewhat effective | high monetary cost | 73 |
| hexachlorobenzene | wastewater | destruction | somewhat effective | high monetary cost | 73 |
| isoproturon | wastewater | destruction | not effective | high monetary cost | 73 |
| pentachlorophenol | wastewater | destruction | effective | high monetary cost | 73 |
| simazine | wastewater | destruction | not effective | high monetary cost | 73 |
| benzotriazole | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| di-2-ethylhexyl phthalate | wastewater | destruction | not effective | high monetary cost | 73 |
| dichloromethane | wastewater | destruction | not effective | high monetary cost | 73 |
| nonylphenol | wastewater | destruction | not effective | high monetary cost | 73 |
| octylphenol | wastewater | destruction | not effective | high monetary cost | 73 |
| pentachlorobenzene | wastewater | destruction | very effective | high monetary cost | 73 |
| perfluorooctanesulfonic acid | wastewater | destruction | not effective | high monetary cost | 73 |
| trichloromethane | wastewater | destruction | not effective | high monetary cost | 73 |
| trifluralin | wastewater | destruction | not effective | high monetary cost | 73 |
| 17α-ethynylestradiol | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| 17β-estradiol | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| carbamazepine | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| clarithromycin | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| diclofenac | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| erythromycin | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| estrone | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| ibuprofen | wastewater | stop spread of plum | somewhat effective  Note: plants take up the ibuprofen |  | 111 |
| metformin | wastewater | destruction | very effective | high monetary cost | 61 |
| sulfamethoxazole | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| triclosan | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| trimethoprim | wastewater | destruction | somewhat effective | high monetary cost | 61 |

Table : Hydrogen Peroxide - Commercially Available, but Not Commonly Used for Wastewater Treatment.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Contaminant | Media | Purpose | Effectiveness | References |
| imidacloprid | wastewater | destruction | not effective | 79 |
| oxadiazon | wastewater | destruction | not effective | 81 |
| triallat | wastewater | destruction | not effective | 81 |
| acridine | wastewater | destruction | not effective | 81 |
| butylated hydroxytoluene | wastewater | destruction | somewhat effective | 81 |
| 17α-ethynylestradiol | wastewater | destruction | not effective | 81 |
| 17β-estradiol | wastewater | destruction | not effective | 81 |
| benzocaine | wastewater | destruction | not effective | 81 |
| caffeine | wastewater | destruction | not effective | 81,97 |
| carbamazepine | wastewater | destruction | not effective | 79,81,99 |
| diclofenac | wastewater | destruction | not effective | 79,81 |
| dioxbenzone | wastewater | destruction | not effective | 81 |
| ibuprofen | wastewater | destruction | not effective | 81 |
| mestranol | wastewater | destruction | not effective | 81 |
| progesterone | wastewater | destruction | not effective | 81 |
| sulfamethoxazole | wastewater | destruction | not effective | 79 |
| triclosan | wastewater | destruction | not effective | 81 |

Table : Membrane Bioreactor - Commercially Available, but Not Commonly Used for Wastewater Treatment.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Contaminant | Media | Purpose | Effectiveness | Relative Cost | References |
| benzotriazole | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| N-Nitrosodimethylamine | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| perfluorobutanoic acid | wastewater | destruction | not effective | medium monetary cost | 61 |
| perfluorohexanoic acid | wastewater | destruction | not effective | medium monetary cost | 61 |
| perfluoropentanoic acid | wastewater | destruction | not effective | medium monetary cost | 61 |
| tetrabromobisphenol A | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| tris(2-chloroethyl)phosphate | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| 17α-ethynylestradiol | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| 17β-estradiol | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| azithromycin | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| carbamazepine | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| ciprofloxacin | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| clarithromycin | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| diclofenac | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| enrofloxacin | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| erythromycin | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| estrone | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| lamotrigine | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| metformin | wastewater | destruction | effective | medium monetary cost | 61 |
| sulfamethoxazole | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| triclosan | wastewater | destruction | somewhat effective | medium monetary cost | 61 |
| trimethoprim | wastewater | destruction | somewhat effective | medium monetary cost | 61 |

Table : Ozone - Commercially Available, but Not Commonly Used for Wastewater Treatment.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Contaminant | Media | Purpose | Effectiveness | Relative Cost | References |
| atrazine | wastewater | destruction | somewhat effective |  | 75 |
| diuron | wastewater | destruction | very effective |  | 78 |
| isoproturon | wastewater | destruction | very effective |  | 78 |
| N,N-diethyl-meta-toluamide | wastewater | destruction | somewhat effective |  | 75 |
| oxadiazon | wastewater | destruction | not effective |  | 81 |
| triallat | wastewater | destruction | not effective |  | 81 |
| acridine | wastewater | destruction | not effective |  | 81 |
| bisphenol a | wastewater | destruction | effective |  | 75 |
| butylated hydroxyanisole | wastewater | destruction | effective |  | 75 |
| butylated hydroxytoluene | wastewater | destruction | not effective to effective depending on application |  | 75,81 |
| butylbenzyl phthalate | wastewater | destruction | effective |  | 75 |
| dioctyl phthalate | wastewater | destruction | effective |  | 75 |
| nonylphenol | wastewater | destruction | somewhat effective |  | 75 |
| octylphenol | wastewater | destruction | effective |  | 75 |
| o-hydroxy atorvastatin | wastewater | destruction | effective |  | 75 |
| perfluorooctanesulfonic acid | wastewater | destruction | very effective |  | 78 |
| p-hydroxy atorvastatin | wastewater | destruction | effective |  | 75 |
| tris(2-chloroethyl)phosphate | wastewater | destruction | somewhat effective |  | 75 |
| tris(2-chloroisopropyl)phosphate | wastewater | destruction | effective |  | 75 |
| 17α-ethynylestradiol | wastewater | destruction | not effective to very effective depending on application | medium monetary cost | 78,81,90 |
| 17β-estradiol | wastewater | destruction | not effective to very effective depending on application | medium monetary cost | 78,81,90 |
| acetaminophen | wastewater | destruction | very effective |  | 75 |
| amoxicillin | wastewater | destruction | very effective |  | 78 |
| androstenedione | wastewater | destruction | very effective |  | 62,94 |
| atenolol | wastewater | destruction | somewhat effective |  | 75 |
| atorvastatin | wastewater | destruction | effective |  | 75 |
| azithromycin | wastewater | destruction | very effective |  | 78 |
| benzocaine | wastewater | destruction | not effective |  | 81 |
| benzophenone | wastewater | destruction | effective |  | 75 |
| benzotriazole | wastewater | destruction | somewhat effective | medium monetary cost | 90 |
| bezafibrate | wastewater | destruction | very effective |  | 78 |
| caffeine | wastewater | destruction | not effective |  | 81 |
| carbamazepine | wastewater | destruction | not effective to very effective depending on the application | medium monetary cost | 75,78,81,90,94 |
| citalopram | wastewater | destruction | effective to very effective | medium monetary cost | 78,90 |
| clarithromycin | wastewater | destruction | very effective |  | 78 |
| clopidogrel | wastewater | destruction | very effective |  | 78 |
| diclofenac | wastewater | destruction | not effective to very effective depending on application | medium monetary cost | 75,78,81,90,94,102 |
| dilantin | wastewater | destruction | somewhat effective |  | 75 |
| dioxbenzone | wastewater | destruction | not effective |  | 81 |
| diphenhydramine | wastewater | destruction | very effective |  | 78 |
| erythromycin | wastewater | destruction | very effective |  | 78 |
| estradiol | wastewater | destruction | effective |  | 75 |
| estrone | wastewater | destruction | effective to very effective | medium monetary cost | 75,78,90,94 |
| fluoxetine | wastewater | destruction | very effective |  | 78 |
| galaxolide | wastewater | destruction | effective |  | 75 |
| gemfibrozil | wastewater | destruction | somewhat effective to very effective depending on application | medium monetary cost | 75,90 |
| hydrochlorothiazide | wastewater | destruction | very effective |  | 78 |
| hydrocodone | wastewater | destruction | effective |  | 75 |
| ibuprofen | wastewater | destruction | not effective to effective | medium monetary cost | 75,78,81,90 |
| iopromide | wastewater | destruction | somewhat effective |  | 75 |
| isoproturon | wastewater | destruction | somewhat effective | medium monetary cost | 90 |
| mecoprop | wastewater | destruction | somewhat effective | medium monetary cost | 90 |
| meprobamate | wastewater | destruction | somewhat effective |  | 75 |
| mestranol | wastewater | destruction | not effective |  | 81 |
| metoprolol | wastewater | destruction | somewhat effective to very effective | medium monetary cost | 78,90 |
| naproxen | wastewater | destruction | somewhat effective to very effective | medium monetary cost | 75,78,90 |
| norfluoxetine | wastewater | destruction | very effective |  | 78 |
| oxybenzone | wastewater | destruction | effective |  | 75 |
| progesterone | wastewater | destruction | not effective to effective depending on application |  | 75,81 |
| propranolol | wastewater | destruction | very effective |  | 78 |
| sulfamethoxazole | wastewater | destruction | effective to very effective | medium monetary cost | 75,78,90,117 |
| testosterone | wastewater | destruction | effective to very effective |  | 75,118 |
| tramadol | wastewater | destruction | very effective |  | 78 |
| triclosan | wastewater | destruction | not effective to very effective depending on application |  | 75,81,94 |
| trimethoprim | wastewater | destruction | very effective | medium monetary cost | 75,78,90 |
| venlafaxine | wastewater | destruction | somewhat effective to very effective depending on application | medium monetary cost | 78,90 |

Table : Reverse Osmosis - Commercially Available, but Not Commonly Used for Wastewater Treatment.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Contaminant | Media | Purpose | Effectiveness | Relative Cost | References |
| atrazine | wastewater | stop continued contamination | very effective |  | 75 |
| N,N-diethyl-meta-toluamide | wastewater | stop continued contamination | very effective |  | 75 |
| bisphenol a | wastewater | stop continued contamination | very effective |  | 75 |
| butylated hydroxyanisole | wastewater | stop continued contamination | very effective |  | 75 |
| butylated hydroxytoluene | wastewater | stop continued contamination | very effective |  | 75 |
| butylbenzyl phthalate | wastewater | stop continued contamination | very effective |  | 75 |
| dioctyl phthalate | wastewater | stop continued contamination | very effective |  | 75 |
| nonylphenol | wastewater | stop continued contamination | very effective |  | 75 |
| octylphenol | wastewater | stop continued contamination | very effective |  | 75 |
| o-hydroxy atorvastatin | wastewater | stop continued contamination | very effective |  | 75 |
| PFAS | wastewater, drinking water, landfill leachate | stop continued contamination | effective | high monetary cost | 88 |
| p-hydroxy atorvastatin | wastewater | stop continued contamination | very effective |  | 75 |
| tris(2-chloroethyl)phosphate | wastewater | stop continued contamination | very effective |  | 75 |
| tris(2-chloroisopropyl)phosphate | wastewater | stop continued contamination | very effective |  | 75 |
| acetaminophen | wastewater | stop continued contamination | effective |  | 75 |
| atenolol | wastewater | stop continued contamination | very effective |  | 75 |
| atorvastatin | wastewater | stop continued contamination | very effective |  | 75 |
| benzophenone | wastewater | stop continued contamination | very effective |  | 75 |
| carbamazepine | wastewater | stop continued contamination | very effective |  | 75 |
| diclofenac | wastewater | stop continued contamination | very effective |  | 75 |
| dilantin | wastewater | stop continued contamination | very effective |  | 75 |
| estradiol | wastewater | stop continued contamination | very effective |  | 75 |
| estrone | wastewater | stop continued contamination | very effective |  | 75 |
| galaxolide | wastewater | stop continued contamination | very effective |  | 75 |
| gemfibrozil | wastewater | stop continued contamination | very effective |  | 75 |
| hydrocodone | wastewater | stop continued contamination | very effective |  | 75 |
| ibuprofen | wastewater | stop continued contamination | very effective |  | 75 |
| iopromide | wastewater | stop continued contamination | very effective |  | 75 |
| naproxen | wastewater | stop continued contamination | very effective |  | 75 |
| oxybenzone | wastewater | stop continued contamination | very effective |  | 75 |
| progesterone | wastewater | stop continued contamination | very effective |  | 75 |
| sulfamethoxazole | wastewater | stop continued contamination | very effective |  | 75 |
| testosterone | wastewater | stop continued contamination | very effective |  | 75 |
| triclosan | wastewater | stop continued contamination | very effective |  | 75 |
| trimethoprim | wastewater | stop continued contamination | very effective |  | 75 |
| meprobamate | wastewater | stop continued contamination | very effective |  | 75 |

Table : Ultrafiltration - Commercially Available, but Not Commonly Used for Wastewater Treatment.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Contaminant | Media | Purpose | Effectiveness | References |
| amoxicillin | wastewater | stop continued contamination | not effective | 92 |
| carbamazepine | wastewater | stop continued contamination | not effective | 92 |
| diclofenac | wastewater | stop continued contamination | not effective | 92 |

Table : Ultrasonication - Commercially Available, but Not Commonly Used for Wastewater Treatment.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Contaminant | Media | Purpose | Effectiveness | References |
| sulfamethoxazole | wastewater | destruction | not effective | 117 |

Table : Ultraviolet light - Commercially Available, but Not Commonly Used for Wastewater Treatment.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Contaminant | Combined with other treatments | Media | Purpose | Effectiveness | References |
| oxadiazon | - | wastewater | destruction | effective | 81 |
| triallat | - | wastewater | destruction | effective | 81 |
| acridine | - | wastewater | destruction | not effective | 81 |
| butylated hydroxytoluene | - | wastewater | destruction | effective | 81 |
| 17β-estradiol | - | wastewater | destruction | effective | 81 |
| benzocaine | - | wastewater | destruction | not effective | 81 |
| caffeine | - | wastewater | destruction | not effective | 81,97 |
| carbamazepine | - | wastewater | destruction | not effective | 81 |
| cephalothin | - | wastewater | destruction | somewhat effective | 93 |
| diclofenac | - | wastewater | destruction | not effective to very effective depending on application  note: took double the time to reduce to zero vs. other very effective treatments | 78,81 |
| dioxbenzone | - | wastewater | destruction | not effective | 81 |
| ibuprofen | - | wastewater | destruction | not effective | 81 |
| mestranol | - | wastewater | destruction | effective | 81 |
| nitrobenzene | - | wastewater | destruction | not effective | 93 |
| progesterone | - | wastewater | destruction | effective | 81 |
| triclosan | - | wastewater | destruction | effective | 103 |
| 17α-ethynylestradiol | - | wastewater | destruction | effective | 81 |
| ampicillin | - | wastewater | destruction | not effective | 93 |
| imidacloprid | free chlorine | wastewater | destruction | effective | 79 |
| carbamazepine | free chlorine | wastewater | destruction | effective | 79 |
| diclofenac | free chlorine | wastewater | destruction | effective | 79 |
| sulfamethoxazole | free chlorine | wastewater | destruction | effective | 79 |
| N,N-diethyl-meta-toluamide | hydrogen peroxide | wastewater | destruction | somewhat effective | 75 |
| oxadiazon | hydrogen peroxide | wastewater | destruction | effective | 81 |
| triallat | hydrogen peroxide | wastewater | destruction | somewhat effective | 81 |
| butylbenzyl phthalate | hydrogen peroxide | wastewater | destruction | effective | 75 |
| 17β-estradiol | hydrogen peroxide | wastewater | destruction | somewhat effective | 81 |
| acetaminophen | hydrogen peroxide | wastewater | destruction | effective | 75 |
| ampicillin | hydrogen peroxide | wastewater | destruction | not effective | 93 |
| atenolol | hydrogen peroxide | wastewater | destruction | effective | 75 |
| atorvastatin | hydrogen peroxide | wastewater | destruction | effective | 75 |
| benzocaine | hydrogen peroxide | wastewater | destruction | not effective | 81 |
| benzophenone | hydrogen peroxide | wastewater | destruction | effective | 75 |
| caffeine | hydrogen peroxide | wastewater | destruction | not effective to somewhat effective | 81,97 |
| carbamazepine | hydrogen peroxide | wastewater | destruction | not effective to somewhat effective | 75,81 |
| cephalothin | hydrogen peroxide | wastewater | destruction | not effective | 93 |
| meprobamate | hydrogen peroxide | wastewater | destruction | effective | 75 |
| mestranol | hydrogen peroxide | wastewater | destruction | effective | 81 |
| progesterone | hydrogen peroxide | wastewater | destruction | somewhat effective to effective | 75,81 |
| testosterone | hydrogen peroxide | wastewater | destruction | effective | 75 |
| triclosan | hydrogen peroxide | wastewater | destruction | somewhat effective to very effective | 75,81,103 |
| trimethoprim | hydrogen peroxide | wastewater | destruction | effective | 75 |
| atrazine | hydrogen peroxide | wastewater | destruction | effective | 75 |
| bisphenol a | hydrogen peroxide | wastewater | destruction | effective | 75 |
| p-hydroxy atorvastatin | hydrogen peroxide | wastewater | destruction | effective | 75 |
| estradiol | hydrogen peroxide | wastewater | destruction | effective | 75 |
| hydrocodone | hydrogen peroxide | wastewater | destruction | effective | 75 |
| iopromide | hydrogen peroxide | wastewater | destruction | effective | 75 |
| imidacloprid | hydrogen peroxide | wastewater | destruction | effective | 79 |
| acridine | hydrogen peroxide | wastewater | destruction | not effective | 81 |
| butylated hydroxyanisole | hydrogen peroxide | wastewater | destruction | effective | 75 |
| butylated hydroxytoluene | hydrogen peroxide | wastewater | destruction | effective | 75,81 |
| dioctyl phthalate | hydrogen peroxide | wastewater | destruction | effective | 75 |
| nonylphenol | hydrogen peroxide | wastewater | destruction | effective | 75 |
| octylphenol | hydrogen peroxide | wastewater | destruction | effective | 75 |
| o-hydroxy atorvastatin | hydrogen peroxide | wastewater | destruction | effective | 75 |
| tris(2-chloroethyl)phosphate | hydrogen peroxide | wastewater | destruction | somewhat effective | 75 |
| tris(2-chloroisopropyl)phosphate | hydrogen peroxide | wastewater | destruction | effective | 75 |
| 17α-ethynylestradiol | hydrogen peroxide | wastewater | destruction | somewhat effective | 81 |
| carbamazepine | hydrogen peroxide | wastewater | destruction | effective | 79 |
| diclofenac | hydrogen peroxide | wastewater | destruction | not effective to very effective depending on application | 75,81,103 |
| diclofenac | hydrogen peroxide | wastewater | destruction | effective | 79 |
| dilantin | hydrogen peroxide | wastewater | destruction | effective | 75 |
| dioxbenzone | hydrogen peroxide | wastewater | destruction | not effective | 81 |
| estrone | ultraviolet light + hydrogen peroxide | wastewater | destruction | effective | 75 |
| galaxolide | hydrogen peroxide | wastewater | destruction | not effective | 75 |
| ibuprofen | hydrogen peroxide | wastewater | destruction | not effective to very effective depending on application | 75,81 |
| naproxen | hydrogen peroxide | wastewater | destruction | somewhat effective | 75 |
| oxybenzone | hydrogen peroxide | wastewater | destruction | somewhat effective | 75 |
| sulfamethoxazole | hydrogen peroxide | wastewater | destruction | effective | 75 |
| sulfamethoxazole | hydrogen peroxide | wastewater | destruction | effective | 79 |
| gemfibrozil | hydrogen peroxide | wastewater | destruction | effective | 75 |
| oxadiazon | ozone | wastewater | destruction | effective | 81 |
| triallat | ozone | wastewater | destruction | not effective | 81 |
| acridine | ozone | wastewater | destruction | not effective | 81 |
| butylated hydroxytoluene | ozone | wastewater | destruction | somewhat effective | 81 |
| 17α-ethynylestradiol | ozone | wastewater | destruction | effective | 81 |
| 17β-estradiol | ozone | wastewater | destruction | effective | 81 |
| amoxicillin | ozone | wastewater | destruction | very effective | 78 |
| benzocaine | ozone | wastewater | destruction | not effective | 81 |
| caffeine | ozone | wastewater | destruction | not effective | 81 |
| carbamazepine | ozone | wastewater | destruction | not effective | 81 |
| diclofenac | ozone | wastewater | destruction | not effective to very effective depending on application | 78,81 |
| dioxbenzone | ozone | wastewater | destruction | not effective | 81 |
| ibuprofen | ozone | wastewater | destruction | not effective | 81 |
| mestranol | ozone | wastewater | destruction | effective | 81 |
| progesterone | ozone | wastewater | destruction | effective | 81 |
| triclosan | ozone | wastewater | destruction | very effective | 81 |

Table : Experimental/Laboratory Scale Technology.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Contaminant | Treatment Technology | Media | Purpose | Effectiveness | Relative Cost | References |
| propyl paraben | activated persulfate using iron-containing magnetic carbon xerogels | wastewater | stop continued contamination | somewhat effective |  | 116 |
| tetracycline | aerobic granular sludge | wastewater | destruction | effective |  | 120 |
| carbamazepine | aluminum oxide | wastewater | stop continued contamination | not effective |  | 100 |
| diclofenac | wastewater | stop continued contamination | not effective |  | 100 |
| atrazine | biofilter (anthracite, sand, activated carbon) | wastewater | stop continued contamination | not effective |  | 76 |
| metolachlor | wastewater | stop continued contamination | not effective |  | 76 |
| tris(2-chloroethyl)phosphate | wastewater | stop continued contamination | not effective |  | 76 |
| atenolol | wastewater | stop continued contamination | not effective |  | 76 |
| carbamazepine | wastewater | stop continued contamination | not effective |  | 76 |
| fluoxetine | wastewater | stop continued contamination | not effective |  | 76 |
| gemfibrozil | wastewater | stop continued contamination | not effective |  | 76 |
| sulfamethoxazole | wastewater | stop continued contamination | somewhat effective |  | 76 |
| 1,4-dioxane | bioremediation | groundwater, drinking water | destruction | effective |  | 82 |
| carbamazepine | carbon nanotubes | wastewater | stop continued contamination | somewhat effective |  | 100 |
| diclofenac | wastewater | stop continued contamination | somewhat effective |  | 100 |
| carbamazepine | carbon nanotubes + aluminum oxide (1:1) | wastewater | stop continued contamination | effective |  | 100 |
| diclofenac | wastewater | stop continued contamination | somewhat effective |  | 100 |
| aniline | cerium and hydrogen sulfite-derived reactive species | wastewater | destruction | somewhat effective | high monetary cost | 74 |
| nitrobenzene | wastewater | destruction | not effective | high monetary cost | 74 |
| rhodamine 6G | wastewater | destruction | effective | high monetary cost | 74 |
| rhodamine B | wastewater | destruction | effective | high monetary cost | 74 |
| caffeine | wastewater | destruction | not effective | high monetary cost | 74 |
| gentian violet | wastewater | destruction | effective | high monetary cost | 74 |
| methyl blue | wastewater | destruction | effective | high monetary cost | 74 |
| norfloxacin | wastewater | destruction | somewhat effective | high monetary cost | 74 |
| sulfamethoxazole | wastewater | destruction | somewhat effective | high monetary cost | 74 |
| atrazine | wastewater | destruction | somewhat effective | high monetary cost | 74 |
| carbamazepine | wastewater | destruction | somewhat effective | high monetary cost | 74 |
| caffeine | compost-derived bio-based substances with electrical potential | wastewater | destruction | not effective |  | 97 |
| estrone | direct photolysis | wastewater | destruction | not effective |  | 106 |
| atenolol | electrodialysis | wastewater | stop continued contamination | very effective |  | 95 |
| caffeine | wastewater | stop continued contamination | very effective |  | 95 |
| carbamazepine | wastewater | stop continued contamination | very effective |  | 95 |
| diclofenac | wastewater | stop continued contamination | very effective |  | 95 |
| furosemide | wastewater | stop continued contamination | very effective |  | 95 |
| hydrochlorothiazide | wastewater | stop continued contamination | very effective |  | 95 |
| ibuprofen | wastewater | stop continued contamination | very effective |  | 95 |
| metoprolol | wastewater | stop continued contamination | very effective |  | 95 |
| trimethoprim | wastewater | stop continued contamination | very effective |  | 95 |
| ibuprofen | enhanced-photocatalysis | wastewater | destruction | somewhat effective |  | 112 |
| ibuprofen | flat sheet dual membrane electrode (2 or greater voltage) | wastewater | destruction | effective | high monetary cost | 110 |
| imidacloprid | fluidized-bed reactor - iron and peroxide | wastewater | destruction | effective |  | 80 |
| tetracycline | geofilter (sand and stevensite) | wastewater | stop continued contamination | effective |  | 119 |
| acetaminophen | hybrid bioreactor | wastewater | destruction | effective |  | 51 |
| atenolol | wastewater | destruction | effective |  | 51 |
| bezafibrate | wastewater | destruction | effective |  | 51 |
| caffeine | wastewater | destruction | effective |  | 51 |
| carbamazepine | wastewater | destruction | effective |  | 51 |
| ciprofloxacin | wastewater | destruction | effective |  | 51 |
| fenofibrate | wastewater | destruction | effective |  | 51 |
| ibuprofen | wastewater | destruction | effective |  | 51 |
| indomethacin | wastewater | destruction | effective |  | 51 |
| ketoprofen | wastewater | destruction | effective |  | 51 |
| mefenamic acid | wastewater | destruction | effective |  | 51 |
| naproxen | wastewater | destruction | effective |  | 51 |
| ofloxacin | wastewater | destruction | effective |  | 51 |
| trimethoprim | wastewater | destruction | effective |  | 51 |
| carbamazepine | hydrogen peroxide + acid washed iron + ultrasonication | wastewater | destruction | effective |  | 99 |
| carbamazepine | hydrogen peroxide + iron + methanol | wastewater | destruction | effective |  | 99 |
| carbamazepine | hydrogen peroxide + iron + pH3-5 | wastewater | destruction | effective |  | 99 |
| carbamazepine | hydrogen peroxide + iron + pH7-9 | wastewater | destruction | not effective |  | 99 |
| carbamazepine | hydrogen peroxide + iron + ultrasonication | wastewater | destruction | not effective |  | 99 |
| carbamazepine | hydrogen peroxide + iron oxide + ultrasonication | wastewater | destruction | not effective |  | 99 |
| carbamazepine | wastewater | destruction | not effective |  | 99 |
| caffeine | hydrogen peroxide + MH0.2 | wastewater | destruction | not effective |  | 97 |
| diazinon | magnetic nanophotocatalysts | drinking water | destruction | somewhat effective | high monetary cost | 77 |
| enrofloxacin hydrochloride (veterinary antibiotic) | drinking water | destruction | somewhat effective | high monetary cost | 77 |
| propachlor | drinking water | destruction | effective | high monetary cost | 77 |
| 4-chlorophenol | drinking water | destruction | not effective | high monetary cost | 83 |
| acid orange 2 | drinking water | destruction | effective | high monetary cost | 77 |
| acid orange 7 | drinking water | destruction | effective | high monetary cost | 77 |
| acridine | drinking water | destruction | effective | high monetary cost | 77 |
| bisphenol a | drinking water | destruction | effective | high monetary cost | 77 |
| blue basic dye | drinking water | destruction | effective | high monetary cost | 77 |
| dibutyl phthalate | drinking water | destruction | effective | high monetary cost | 77 |
| fluoresein | drinking water | destruction | effective | high monetary cost | 77 |
| formic acid | drinking water | destruction | somewhat effective | high monetary cost | 77 |
| methyl orange | drinking water | destruction | effective | high monetary cost | 77 |
| neutral red | drinking water | destruction | effective | high monetary cost | 77 |
| nonylphenol | drinking water | destruction | effective | high monetary cost | 77 |
| octylphenol | drinking water | destruction | effective | high monetary cost | 77 |
| orange 2 | drinking water | destruction | effective | high monetary cost | 77 |
| phenol | drinking water | destruction | effective | high monetary cost | 77 |
| procion red MX-5B | drinking water | destruction | effective | high monetary cost | 77 |
| quinoline | drinking water | destruction | effective | high monetary cost | 77 |
| reactive black 5 | drinking water | destruction | effective | high monetary cost | 77 |
| red acid G | drinking water | destruction | effective | high monetary cost | 77 |
| red basic dye | drinking water | destruction | effective | high monetary cost | 77 |
| rhodamine B | drinking water | destruction | effective | high monetary cost | 77 |
| thymol blue | drinking water | destruction | effective | high monetary cost | 77 |
| dimethyl phthalate | drinking water | destruction | somewhat effective | high monetary cost | 77 |
| ibuprofen | drinking water | destruction | somewhat effective | high monetary cost | 77 |
| methylene blue | drinking water | destruction | effective | high monetary cost | 77 |
| naproxen | drinking water | destruction | somewhat effective | high monetary cost | 77 |
| sucrose | drinking water | destruction | effective | high monetary cost | 77 |
| cocktail of five commonly used pharmaceuticals, carbamazepine, diclofenac, gabapentin, oxazepame, and fluconazole | magnetoelectric nanocatalysts + bismuth ferrite | wastewater | stop continued contamination | not effective |  | 101 |
| cocktail of five commonly used pharmaceuticals, carbamazepine, diclofenac, gabapentin, oxazepame, and fluconazole | magnetoelectric nanocatalysts + cobalt (II) ferrite | wastewater | stop continued contamination | not effective |  | 101 |
| cocktail of five commonly used pharmaceuticals, carbamazepine, diclofenac, gabapentin, oxazepame, and fluconazole | magnetoelectric nanocatalysts + magnetostrictive cobalt (II) ferrite cores coated with multiferroic bismuth (III) ferrite shells | wastewater | stop continued contamination | effective |  | 101 |
| galaxolide | microalgae mono-digestion | wastewater | destruction | somewhat effective | medium monetary cost | 107 |
| methyl dihydrojasmonate | wastewater | destruction | somewhat effective | medium monetary cost | 107 |
| tonalide | wastewater | destruction | somewhat effective | medium monetary cost | 107 |
| triclosan | wastewater | destruction | somewhat effective | medium monetary cost | 107 |
| diclofenac | molecularly imprinted polymer | wastewater | stop continued contamination | somewhat effective |  | 104 |
| benzotriazole | moving bed biofilm reactor | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| 17α-ethynylestradiol | wastewater | destruction | effective | high monetary cost | 61 |
| 17β-estradiol | wastewater | destruction | effective | high monetary cost | 61 |
| azithromycin | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| carbamazepine | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| ciprofloxacin | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| clarithromycin | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| diclofenac | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| enrofloxacin | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| erythromycin | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| estrone | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| sulfamethoxazole | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| triclosan | wastewater | destruction | effective | high monetary cost | 61 |
| trimethoprim | wastewater | destruction | somewhat effective | high monetary cost | 61 |
| carbamazepine | peracetic acid and sunlight | wastewater | destruction | somewhat effective | high monetary cost | 71 |
| diclofenac | wastewater | destruction | effective | high monetary cost | 71 |
| sulfamethoxazole | wastewater | destruction | somewhat effective | high monetary cost | 71 |
| diclofenac | photocatalysis | wastewater | destruction | very effective |  | 105 |
| hydrochlorothiazide | photoelectrochemical + cadmium selenium quantum dots + tin oxide nanotubes nanotubes | wastewater | destruction | effective |  | 108 |
| ketoprofen | photoelectrochemical + tungsten oxide and beta25 thin film + with electrical potential | wastewater | destruction | effective |  | 113 |
| levofloxacin | wastewater | destruction | effective |  | 113 |
| ketoprofen | photoelectrochemical + tungsten oxide thin film + no electrical potential | wastewater | destruction | not effective |  | 113 |
| levofloxacin | wastewater | destruction | effective |  | 113 |
| ketoprofen | photoelectrochemical + tungsten oxide thin film + with electrical potential | wastewater | destruction | somewhat effective |  | 113 |
| levofloxacin | wastewater | destruction | effective |  | 113 |
| ibuprofen | photo-Fenton | wastewater | destruction | somewhat effective |  | 112 |
| PFAS | precipitation + flocculation + coagulation | drinking water, surface water, wastewater | stop continued contamination | effective | low monetary cost | 88 |
| PFAS | redox manipulation | wastewater, drinking water, surface water, groundwater, soil, landfill leachate, landfill | destruction, stop spread of plume | effective | medium monetary cost | 88 |
| diclofenac | sonolysis | wastewater | destruction | not effective |  | 105 |
| diclofenac | sonophotocatalysis | wastewater | destruction | very effective |  | 105 |
| ibuprofen | wastewater | destruction | somewhat effective |  | 112 |
| ibuprofen | sonophoto-Fenton | wastewater | destruction | somewhat effective |  | 112 |
| azo dye reactive orange 16 | titanium oxide | wastewater | destruction | effective |  | 84 |
| ibuprofen | titanium oxide + iron + sonolysis | wastewater | destruction | very effective |  | 112 |
| ibuprofen | titanium oxide nanofibers combined with boron nitride nanosheets | wastewater | destruction | somewhat effective | high monetary cost | 109 |
| ibuprofen | titanium oxide nanofibers combined with boron nitride nanosheets under ultraviolet light | wastewater | destruction | effective | high monetary cost | 109 |
| amoxicillin | ultrafiltration + activated carbon adsorption + ultrasound irradiation | wastewater | stop continued contamination | very effective |  | 92 |
| carbamazepine | wastewater | stop continued contamination | very effective |  | 92 |
| diclofenac | wastewater | stop continued contamination | very effective |  | 92 |
| bisphenol a | ultrasonication | wastewater | destruction | effective |  | 85 |
| diclofenac | wastewater | destruction | somewhat effective |  | 102 |
| linear alkylbenzene sulfonates | wastewater | destruction | somewhat effective |  | 114 |
| diclofenac | ultrasonication + ozone | wastewater | destruction | effective |  | 102 |
| sulfamethoxazole | wastewater | destruction | effective |  | 117 |
| carbamazepine | ultraviolet light + chloramine | wastewater | destruction | somewhat effective |  | 98 |
| carbamazepine | ultraviolet light + carbon nanotubes + titanium oxide | wastewater | destruction | very effective |  | 83 |
| phenol | wastewater | destruction | very effective |  | 83 |
| rhodamine B | wastewater | destruction | very effective |  | 83 |
| acid yellow 36 | wastewater | destruction | effective |  | 83 |
| acridine | wastewater | destruction | very effective |  | 83 |
| direct Red 23 | wastewater | destruction | not effective |  | 83 |
| direct Red 31 | wastewater | destruction | not effective |  | 83 |
| methylene blue | wastewater | destruction | somewhat effective |  | 83 |
| nitrobenzene | wastewater | destruction | very effective |  | 83 |
| rhodamine 6G | wastewater | destruction | effective |  | 83 |
| caffeine | ultraviolet light + hydrogen peroxide + MH0.2 | wastewater | destruction | very effective |  | 97 |
| diuron | ultraviolet light + ozone + titanium oxide | wastewater | destruction | very effective |  | 78 |
| isoproturon | wastewater | destruction | very effective |  | 78 |
| 17α-ethynylestradiol | wastewater | destruction | very effective |  | 78 |
| 17β-estradiol | wastewater | destruction | very effective |  | 78 |
| amoxicillin | wastewater | destruction | very effective |  | 78 |
| azithromycin | wastewater | destruction | very effective |  | 78 |
| bezafibrate | wastewater | destruction | very effective |  | 78 |
| carbamazepine | wastewater | destruction | very effective |  | 78 |
| citalopram | wastewater | destruction | very effective |  | 78 |
| clarithromycin | wastewater | destruction | very effective |  | 78 |
| clopidogrel | wastewater | destruction | very effective |  | 78 |
| diclofenac | wastewater | destruction | very effective |  | 78 |
| diphenhydramine | wastewater | destruction | very effective |  | 78 |
| erythromycin | wastewater | destruction | very effective |  | 78 |
| estrone | wastewater | destruction | very effective |  | 78 |
| fluoxetine | wastewater | destruction | very effective |  | 78 |
| hydrochlorothiazide | wastewater | destruction | very effective |  | 78 |
| ibuprofen | wastewater | destruction | very effective |  | 78 |
| metoprolol | wastewater | destruction | very effective |  | 78 |
| naproxen | wastewater | destruction | very effective |  | 78 |
| norfluoxetine | wastewater | destruction | very effective |  | 78 |
| propranolol | wastewater | destruction | very effective |  | 78 |
| sulfamethoxazole | wastewater | destruction | very effective |  | 78 |
| tramadol | wastewater | destruction | very effective |  | 78 |
| trimethoprim | wastewater | destruction | very effective |  | 78 |
| venlafaxine | wastewater | destruction | very effective |  | 78 |
| ampicillin | ultraviolet light + persulfate | wastewater | destruction | somewhat effective |  | 93 |
| cephalothin | wastewater | destruction | somewhat effective |  | 93 |
| nitrobenzene | wastewater | destruction | somewhat effective |  | 93 |
| oxadiazon | ultraviolet light + titanium oxide | wastewater | destruction | effective |  | 81 |
| triallat | wastewater | destruction | very effective |  | 81 |
| 17β-estradiol | wastewater | destruction | effective to very effective |  | 78,81 |
| mestranol | wastewater | destruction | very effective |  | 81 |
| progesterone | wastewater | destruction | somewhat effective |  | 81 |
| propranolol | wastewater | destruction | very effective |  | 78 |
| tramadol | wastewater | destruction | very effective |  | 78 |
| triclosan | wastewater | destruction | somewhat effective |  | 81 |
| trimethoprim | wastewater | destruction | very effective |  | 78 |
| venlafaxine | wastewater | destruction | very effective |  | 78 |
| isoproturon | wastewater | destruction | very effective |  | 78 |
| diuron | wastewater | destruction | very effective |  | 78 |
| acridine | wastewater | destruction | not effective |  | 81 |
| butylated hydroxytoluene | wastewater | destruction | not effective |  | 81 |
| 17α-ethynylestradiol | wastewater | destruction | Somewhat effective to effective |  | 78,81 |
| amoxicillin | wastewater | destruction | very effective  note: took double the time to reduce to zero vs. other very effective treatments |  | 78 |
| azithromycin | wastewater | destruction | very effective |  | 78 |
| benzocaine | wastewater | destruction | not effective |  | 81 |
| bezafibrate | wastewater | destruction | very effective |  | 78 |
| caffeine | wastewater | destruction | not effective |  | 81 |
| Carbamazepine | wastewater | destruction | very effective |  | 78 |
| carbamazepine | wastewater | destruction | not effective |  | 81 |
| citalopram | wastewater | destruction | very effective |  | 78 |
| clarithromycin | wastewater | destruction | very effective |  | 78 |
| clopidogrel | wastewater | destruction | very effective |  | 78 |
| diclofenac | wastewater | destruction | not effective to very effective depending on application  note: took double the time to reduce to zero vs. other very effective treatments |  | 78,81 |
| dioxbenzone | wastewater | destruction | somewhat effective |  | 81 |
| diphenhydramine | wastewater | destruction | very effective |  | 78 |
| erythromycin | wastewater | destruction | somewhat effective |  | 78 |
| estrone | wastewater | destruction | somewhat effective to effective |  | 78,106 |
| fluoxetine | wastewater | destruction | very effective |  | 78 |
| hydrochlorothiazide | wastewater | destruction | very effective |  | 78 |
| ibuprofen | wastewater | destruction | not effective to very effective depending on application |  | 78 |
| metoprolol | wastewater | destruction | very effective |  | 78 |
| naproxen | wastewater | destruction | very effective |  | 78 |
| norfluoxetine | wastewater | destruction | very effective |  | 78 |
| sulfamethoxazole | wastewater | destruction | very effective |  | 78 |
| amoxicillin | ultraviolet light + visible light | wastewater | destruction | not effective |  | 78 |
| Phenol | ultraviolet light + visible light + carbon nanotube + titanium oxide | wastewater | destruction | very effective |  | 83 |
| methylene orange | wastewater | destruction | very effective |  | 83 |
| perfluorooctanesulfonic acid | ultraviolet light + visible light + ozone + titanium oxide | wastewater | destruction | very effective |  | 78 |
| perfluorooctanesulfonic acid | ultraviolet light + visible light + titanium oxide | wastewater | destruction | very effective |  | 78 |
| estrone | ultraviolet light + zinc oxide | wastewater | destruction | effective |  | 106 |
| metronidazole | visible light + aerobic conditions | wastewater | destruction | somewhat effective |  | 115 |
| metronidazole | visible light + aerobic conditions + iron | wastewater | destruction | somewhat effective |  | 115 |
| metronidazole | visible light + anaerobic conditions | wastewater | destruction | very effective |  | 115 |
| phenol | visible light + carbon nanotube + titanium oxide | wastewater | destruction | not effective to very effective depending on the type and structure of the carbon nanotube |  | 83 |
| dinitrophenol | visible light + carbon nanotubes + titanium oxide | wastewater | destruction | very effective |  | 83 |
| 4-chlorophenol | Zinc + carbon nanotubes + oxygen | wastewater | destruction | very effective |  | 77 |

Appendix C: Review of State Legislation

1. **Enacted**
   1. CALIFORNIA

2017 Legis. Bill Hist. CA S.B. 1422

This bill, although not directly affecting wastewater treatment, acknowledges that microplastics are not caught during treatment in WWTPs and are then released into the environment. This bill suggests exploratory testing of microplastics in drinking water, acknowledging that wastewater effluent is a possible source of microplastic pollution.

* 1. ILLINOIS

110 ILCS 425/21

With the passage of 110 ILCS 425/21, the state has ordered a CEC report for any chemicals that are commonly found in WWTP runoff and recognized by the U.S. Environmental Protection Agency. A review of the scientific literature and state and federal regulations are to be included in the report. (This report is the one requested from this bill.)

* 1. MAINE

2019 Bill Text ME E.O. 5

Maine’s governor has issued an executive order to do a study on CEC, specifically PFAS contamination related to public health and the environment. This study requests expert knowledge from WWTP operators, drinking water supply professionals, and biosolid and residual management professionals.

* 1. NEW HAMPSHIRE

N.H. Rev. Stat. Ann. § 126-A:79-a

The State of New Hampshire has enacted and codified N.H. Rev. Stat. Ann. § 126-A:79-a, a statute that establishes a commission to study the environmental impact from perfluorinated chemicals (PFAS) in air, soil, and water. The bill specifies that the sources and impact of wastewater discharge will be tested from one wastewater treatment plant in the state.

1. **Introduced, But Not Enacted**
   1. MINNESOTA

2019 MN S.B. 2201

Among other things, S.B. 2201 appropriates money ($415,000) from “The Trust Fund to the Board of Regents of the University of Minnesota” to help find the most efficient and safe way to remove harmful fluorinated pharmaceuticals[[5]](#footnote-5) in the wastewater treatment process and how to develop alternatives to these compounds that are environmentally harmful. The amount of $250,000 would be used in the first year to develop methods to remove the polyfluoroalkyl substances (PFAS) and microplastics from wastewater. It has a low passage outlook for the next stage.

2019 MN H.B. 2032

A similar bill, House Bill 2032, appropriates $415,000 the first year from the Board of Regents of the University of Minnesota to help determine the most effective way to remove fluorinated pharmaceuticals during the wastewater treatment process. By removing contaminants from wastewater, $250,000 is planned to be used to help develop methods to remove polyfluoroalkyl substances and microplastics from wastewater before they are released into the environment. This bill has a high chance of passing at the next stage.

* 1. NORTH CAROLINA

2019 Bill Text NC S.B. 518

This bill calls for the establishment of a “PFAS Task Force” in order to identify and analyze PFAS and other chemical contaminants of emerging concern. In addition to studying these chemicals, the bill calls on the task force to study how contaminants reach humans in regard to wastewater discharges, among other pathways.

* 1. PENNSYLVANIA

2019 Bill Text PA H.B. 1226 [April 29, 2019]

This bill amends the 1988 Hazardous Sites Cleanup Act and adds that no municipality or public water supplier will be considered a responsible person on account of PFAS in wastewater treatment sludge, water supply treatment residuals, spent filter media, or similar facility operational wastes. This bill has a medium chance of passing at the next stage in the process.

2019 Bill Text PA H.B. 1364 [May 29, 2019]

This bill amends the 1988 Hazardous Sites Cleanup Act with the same statement as PA H.B. 1226 for WWTPs. PA H.B. 1364 adds extensive language on drinking water contaminated with emerging contaminants and PFAS.

Neither bill has been enacted and neither has explicitly failed.

* 1. VERMONT

2019 Bill Text VT H.B. 263

This introduced bill would find that perfluoroalkyl and polyfluoroalkyl substances and other perfluorochemicals are widely used in industry and consumer products. It would find that Vermont water standards do not currently require the treatment of PFAS in wastewater. The bill attempts to amend the Vermont Water Quality Standards to include PFAS limitations on surface waters in the state to ensure that wastewater discharge does not further contribute to PFAS in the environment. The limitations would apply to PFAS, including perfluorooctanoic acid, perfluorooctanesulfonic acid, perfluorohexane sulfonic acid, perfluoroheptanoic acid, and perfluorononanoic acid. This bill has a low chance of passing at the next stage.

2019 Bill Text VT S.B. 49

This bill was enacted in Vermont, but the part referring to wastewater in the bill was stricken. It would have required landfills to treat leachate for polyfluoroalkyl substances before it is delivered to a wastewater treatment facility or facility where the waters would be used by the state.

2019 Bill Text VT H.B. 98

This bill would require the General Assembly of Vermont to acknowledge that PFAS, pharmaceuticals, and PPCPs have been found in effluent from wastewater treatment plants, among other sources of water. This bill also states that recent studies have shown that there are contaminants of emerging concern that act as endocrine disruptors at parts per billion or parts per trillion. The contaminants do not break down in the environment for a very long time, affecting both humans and wildlife. This bill further acknowledges that many CECs are not regulated by federal or state standards for drinking water or wastewater. It would require the Agency of Natural Resources in Vermont to submit a report on landfill leachate. This bill is recorded as having a low chance of passing at the next stage.

1. **Failed**
   1. HAWAII

2017 Bill Text HI H.B. 2042

This bill failed after its introduction in the House. It called for the legislature to appropriate funds to comply with obligations for monitoring the islands’ water safety, with particular attention paid to contaminants of emerging concern from wastewater treatment plant outfalls, injection wells, and cesspools.

* 1. MINNESOTA

2015 MN H.B. 846

Minnesota House Bill 846 was vetoed by the governor in 2015. It would have helped to address existing and emerging wastewater treatment challenges including the emergence of new and other unregulated contaminants in wastewater treatment plants.

2015 MN S.B. 1305

Minnesota Senate Bill 1305 (2015) failed after its introduction. This bill would have used design teams with scientific and technical expertise pertaining to wastewater management and treatment to help address issues including the emergence of new and other unregulated contaminants in wastewater.

* 1. MICHIGAN

2018 MI H.B. 6245

Michigan H.B. 6245 would have appropriated funding for response activities to address public health and environmental problems with PFAS.

* 1. NEW HAMPSHIRE

2017 N.H. H.B. 485

This bill would have adopted certain groundwater standards, acknowledging that it would have an impact on publicly owned wastewater treatment facilities in the state. It assumes that most facilities would exceed standard contaminant levels allowed and would require extra treatment for the wastewater. New response plans, additional samples, and larger discharge zones would be needed to comply.

* 1. NORTH CAROLINA

2017 Bill Text NC H.B. 968

This bill would have appropriated over $6 million to collect and analyze data relating to PFAS. Included with this funding would have been money to hire employees to attempt to identify potential sources of contamination in wastewater.

2017 Bill Text NC H.B. 972/ 2017 Bill Text NC S.B. 724

These bills would have allotted $450,000 from the General Fund to the Division of Water Resources of the Department of Environmental Quality. Part of this grant would be given to a program that looks for PFAS in drinking water. The bills would have indirectly examined wastewater contaminants as well.

* 1. PENNSYLVANIA

2019 Bill Text PA S.B. 582

This bill would have made public water suppliers “not responsible” for PFOA and PFAS from wastewater treatment sludge or residuals where the presence of the substances is due to chemical characteristics of the water source or release into the wastewater treatment plant.

1. **Firefighting Foam Regulations**

Arizona, Georgia, Kentucky, Michigan, New Hampshire, New York, Minnesota, Washington, and Wisconsin all have bills in the process of or enacted to help protect firefighters from the harmful chemicals found in firefighting foam.

Protecting Firefighters from Adverse Substances Act of 2019, 116 S. 2353, 2019 S. 2353, 116 S. 2353

This bill was introduced into the U.S. Senate to protect firefighters from adverse substances, such as PFAS, that could be present.

1. **No Regulations**

The following states have no regulations for wastewater treatment plants, but there are regulations for either drinking water standards or source water standards: Alaska, California, Colorado, Connecticut, Delaware, Kentucky, Maine, Massachusetts, Michigan, Minnesota, New Hampshire, New Jersey, New Mexico, New York, North Carolina, Pennsylvania, Rhode Island, Vermont, West Virginia, and Wisconsin.

No regulations related to contaminants of emerging concern were found for these states: Alabama, Arizona, Arkansas, Florida, Georgia, Idaho, Indiana, Iowa, Kansas, Mississippi, Missouri, Montana, Nebraska, Nevada, North Dakota, Ohio, Oklahoma, Oregon, South Carolina, South Dakota, Tennessee, Texas, Utah, Virginia, and Wyoming.

1. **Federal Litigation Pending**

*Tenn. Riverkeeper, Inc. v. 3M Co.,* 234 F. Supp. 3d 1153 (N.D. Ala. 2017)

The defendants’ motion to dismiss was denied. In its complaint, Tennessee Riverkeeper alleges that there were PFOA and PFOS in wastewater and sludge discharge from a 3M plant. Because of the Federal Rules of Civil Procedure, the court must accept as true the facts on the well-pleaded complaint; therefore, the court cannot grant the motion to dismiss.

*W. Morgan-East Lawrence Water & Sewer Auth. v. 3M Co.,* 208 F. Supp. 3d 1227 (N.D. Ala. 2016)

The defendants discharge wastewaters containing PFOA, PFOS, and related chemicals in the Tennessee River. 3M releases the water into the Decatur Utilities Wastewater Treatment Plant, and the WWTP in turn discharges it into the Tennessee River. Although water is treated, these chemicals remain in the water.

The plaintiffs allege personal injuries from exposure to PFOA and PFOS in the water supply based on theories of negligence, nuisance, abatement of nuisance, trespass, battery, and wantonness. The court dismissed the trespass claim with prejudice, and dismissed the negligence, nuisance, abatement of nuisance, battery, and wantonness claims without prejudice.

*King v. W. Morgan-East Lawrence Water & Sewer Auth.,* No. 5:17-cv-01833-AKK, 2019 U.S. Dist. LEXIS 40191 (N.D. Ala. Mar. 13, 2019)

This case has the same background information as the W. Morgan-East Lawrence Water & Sewer Auth. V. 3M Co. described in the first paragraph in that section. The plaintiffs have asserted claims of negligence, nuisance, fraudulent concealment, and wantonness. One of the defendants, 3M, has filed three motions: a motion to stay with respect to another pending case they are involved in, a motion to dismiss, and a motion to file a supplemental brief. The court has granted the motion to dismiss with prejudice with respect to the private nuisance claims and has denied the motion to dismiss on the other claims. Additionally, the court has denied the motion to stay, as well as the motion to file a supplemental brief.

*Rhodes v. E.I. Du Pont de Nemours & Co.,* 657 F. Supp. 2d 751 (S.D. W. Va. 2009)

Plaintiffs allege that their injury stems in part from the Washington Works Plant that emits PFOA into the water supply. For the tort theories of negligence, gross negligence, and reckless, willful, and wanton conduct, private nuisance, trespass, battery, and public nuisance, the defendant’s motion for summary judgment was granted.

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1. Negative removal efficiency means that the contaminant was concentrated (increased per volume of liquid) during treatment. [↑](#footnote-ref-1)
2. See Tenn. Riverkeeper, Inc. v. 3M Co., 234 F. Supp. 3d 1153 (N.D. Ala. 2017); W. Morgan-East Lawrence Water & Sewer Auth. v. 3M Co., 208 F. Supp. 3d 1227 (N.D. Ala. 2016); King v. W. Morgan-East Lawrence Water & Sewer Auth., No. 5:17-cv-01833-AKK, 2019 U.S. Dist. LEXIS 40191 (N.D. Ala. Mar. 13, 2019) in Appendix C. [↑](#footnote-ref-2)
3. See 110 ILCS 425/21; 2019 Bill Text ME E.O. 5; N.H. Rev. Stat. Ann. § 126-A:79-a in Appendix C. [↑](#footnote-ref-3)
4. See 2019 MN S.B. 2201; 2019 MN H.B. 2032; 2019 Bill Text NC S.B. 518; 2019 Bill Text PA H.B. 1226; 2019 Bill Text PA H.B. 1364; 2019 Bill Text PA H.B. 1226; 2019 Bill Text VT H.B. 263; 2019 Bill Text VT S.B. 49; 2019 Bill Text VT H.B. 98 in Appendix C. [↑](#footnote-ref-4)
5. Experts debate as to whether fluorinated pharmaceuticals should be classified under PFAS [↑](#footnote-ref-5)