HANDBOOK ON REDUCING CHEMICAL FOOTPRINTS

Chapter 6. Water Treatment: Chemicals of Concern are not Treated or Removed

This chapter examines basic requirements of US municipal water treatment and their shortcomings with respect to chemicals of concern. Treating water to achieve drinking and wastewater quality standards is mandated under federal law. However, existing regulations rarely target chemicals of concern and generally do not identify specific contaminant removal methods. Researchers have detected many unregulated chemicals of concern in the water supply. This means that current wastewater and drinking water treatment methods are not removing chemicals of concern at levels sufficient to bring the concentrations below detection levels.

The effectiveness of current water treatment methods for chemicals of concern and the possibility that new methods targeted at chemicals of concern can fill the gaps are the issues considered in the sections that follow. The section starts with a brief review of the laws requiring water treatment to meet national water quality standards and the treatment processes adopted to meet those requirements, including treatment of drinking water and municipal wastewater. The discussion considers current exemptions from wastewater treatment requirements, such as runoff and septic systems. The range of potential contaminants threatening the water supply is broader than the list of those required by law to be measured, removed and reported. Some municipal water treatment facilities are adopting advanced removal mechanisms to address chemicals of concern in wastewater and drinking water. Some of these new treatment options are discussed with both promise and shortcomings considered.

Federal Laws Requiring Water Treatment

Direct Discharge of Industrial Wastewater into the Cuyahoga River, 1973

National adoption of mandatory community water treatment standards stands out as one of the major achievements of the 1970s environmental movement in the United States. Prior to this, there were no US national standards for water quality or for controlling the release of contaminants into water systems. In most communities, untreated sewage from both municipal and industrial sources was directly released into rivers, streams, lakes and coastal waters.

The lack of water treatment standards before the 1970s reflected the once-common aphorism, “dilution is the solution to pollution.” Historically, small populations managed their wastes through direct dumping into large bodies of waters, including rivers and lakes. Organic matter, such as human waste and vegetable remains, became food sources for other life forms, including animals, bacteria and fungi. The visible remains were washed away. Dumping waste into the water appeared to be an effective solution. However, as the volume of waste grew, it didn't just "wash away." Chemicals from industrial production and personal use were added to the organic waste being dumped, and were not being broken down. Many rivers became open sewers. Dilution could not restore water quality.

Clean Water Act:
"A permit for every pipe," requiring treatment of wastewater from specific sources before release back into the water system.

Safe Drinking Water Act:
Treatment of water before delivery to homes and businesses.

Increasing knowledge and public interest in the threats to human health and the environment from the use and release of various substances into water, air and land systems led lawmakers to adopt an unprecedented series of tough environmental regulations. The decade of the 1970s concluded with the passage of 27 environmental protection laws, as well as hundreds of administrative regulations to implement these laws.[1]

Two primary sets of laws regulate water quality. The Federal Water Pollution Control Act of 1972 set the basic framework for water pollution control across the United States. With subsequent amendments,[2] the law became commonly known as the Clean Water Act (CWA) and is the principal law governing water quality of the nation's waterways. The objective of the CWA as enacted is "to restore and maintain the chemical, physical and biological integrity of the Nation's waters."[3] The focus is on general water quality, including goals of eliminating pollution discharges into all navigable waters and achieving fishable and swimmable water quality levels across the US. The Clean Water Act is designed to ensure water quality by controlling discrete point sources of pollution discharges. All polluted waters being discharged from factories and other industrial sources as well as municipal wastewater treatment plants must be treated for specific contaminants before being released back into the general water system. The Clean Water Act requires "a permit for every pipe."

The second primary law governing water quality was enacted in 1974 as the Safe Drinking Water Act (SDWA). While the Clean Water Act focuses on cleaning up dirty water before it is discharged and sent downriver, the SDWA was designed to ensure that water is clean and meets drinking water quality standards before it is delivered to consumers through municipal water supply systems. Under this act, public water systems are required to supply water that is free from biological, chemical and physical contaminants. Initial regulatory efforts focused on water

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[1] US Environmental Protection Agency, "Laws and Executive Orders," list with summaries available at www2.epa.gov/laws-regulations/laws-and-executive-orders.

[2] Three amendments added substantially to the scope and authority of the 1972 law: the Clean Water Act of 1977; the Water Quality Act of 1987; and the Oil Pollution Act of 1990.

[3] Clean Water Act, Title 33, US Code §1251.

treatment alone. Today, the SDWA is seen as a system that protects drinking water from its source to the tap.

Together, these laws create the foundation for water treatment procedures applied nationwide. Adoption of these important environmental laws in the 1970s resulted in significant water quality improvements. However, these laws do not cover all potentially harmful contaminants. Chapter 7 explains how decisions are made about what will be regulated, including obstacles to adopting new rules to control chemicals of emerging concern.

Water Treatment Overview

Public water systems are responsible for two separate water treatment processes. Water is treated prior to distribution for drinking water consumption and other uses, and then is treated once again when it returns as wastewater and prior to its release back into the environment. Municipal drinking water treatment plants are separate facilities from wastewater treatment plants; they can be thought of as the intake and outflow of the municipal water system, respectively. In between these two community treatment facilities is a network of distribution pipes carrying clean water to consumers and wastewater away. The intake and outflow typically use the same source, such as a river or lake, although not at the same location.

Two Ends of Water Treatment: Drinking Water Supply & Wastewater Disposal

Drinking water is withdrawn from a lake or river and sent through a water purification plant before delivery to homes and businesses. Wastewater is then piped to the wastewater treatment plant after which it is discharged from the publicly owned treatment works (POTW) back into the lake or river.
Source: U.S. EPA

Drinking Water Treatment

Drinking water can be drawn from the ground (well water or aquifers) and from surface sources (lakes, reservoirs, rivers). Depending on the purity of the individual source, different types and levels of treatment are required to protect public health and meet national drinking water quality standards established under the Safe Drinking Water Act. Generally, ground water tends to be cleaner than surface water because it has less exposure to pollutants and the water that occupies the aquifer is naturally filtered. Many public water systems drawing ground water do not have to treat their water to meet federal water standards. Surface water, however, is exposed to a variety of pollutants, both natural and anthropogenic, requiring a greater degree of treatment.

The EPA sets and periodically revises National Primary Drinking Water Regulations to limit the levels of contaminants that pose health risks when present in drinking water supplies and that are known or suspected to occur in public water systems. Today, national standards exist for 90 contaminants, including inorganic chemicals, organic chemicals, radionuclides, and microorganisms.[4] Water treatment processes are constructed to regularly measure and then remove or disinfect these listed contaminants. The EPA also sets National Secondary Drinking Water Regulations that are non-enforceable guidelines that provide recommendations for contaminants that may cause negative cosmetic or aesthetic effects, such as skin or tooth discoloration, or taste, odor and color impacts on the water itself.

Focus of Drinking Water Treatment Processes

Remove impurities in the raw water; render the water safe and clean; and meet the drinking water quality standards.
Specific treatment depends on the physical, chemical and bacteriological characteristics of the raw water.

Except for pesticides (atrazine, glyphosate), none of the contaminants of concern discussed in this handbook are directly regulated under the primary or secondary federal drinking water regulations. However, following congressional passage of the 1996 Safe Drinking Water Act Amendments, EPA launched a process for screening potential endocrine-disrupting chemicals. In November 2012, EPA released a list of approximately 10,000 chemicals included in the Endocrine Disruptor Screening Program (EDSP) "Universe of Chemicals."[5] Only some will be screened for their potential effects on the endocrine system. It is unclear if new regulatory standards will be developed.

People often assume that a rigorous water treatment process will remove any unwanted contaminants from the water supply. Existing filtration methods might remove chemicals not specifically targeted. Given recent findings of unregulated chemicals in drinking water samples from water utilities across the US, current drinking water treatment systems cannot be relied on to eliminate the whole range of chemicals of concern.[6]

Drinking water typically passes through multiple stages in the treatment process: Coagulation / flocculation, sedimentation, filtration, and disinfection.[7] The important first target is to remove large and small particles from the water. Large particles, such as trash and dead leaves, are caught in screens and removed at the outset. Smaller particles are removed through several

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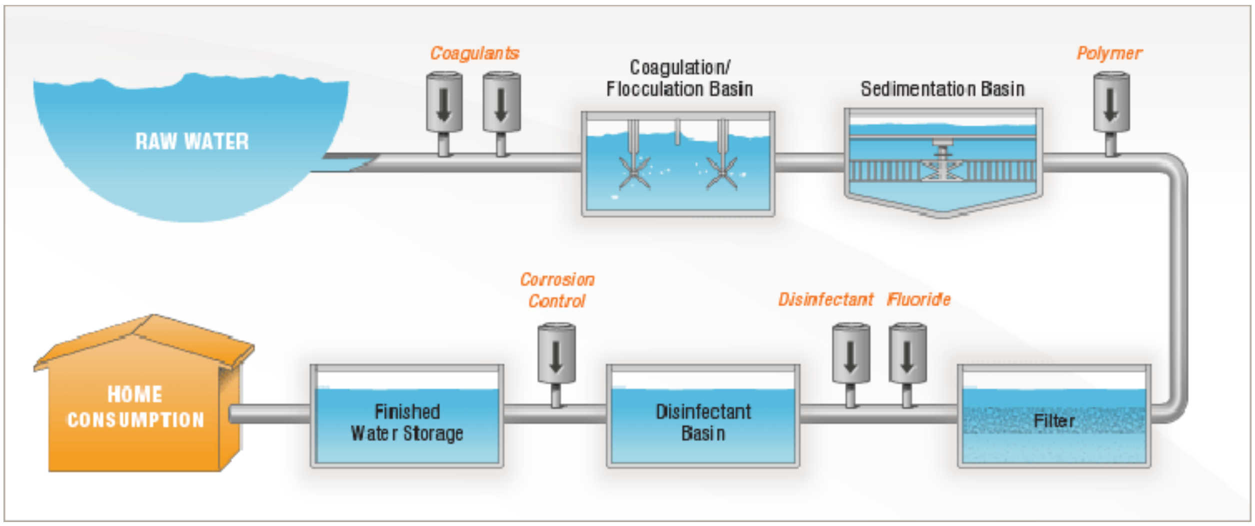
[4] US Environmental Protection Agency, Office of Water, National Primary Drinking Water Standards (water.epa.gov/drink/contaminants/index.cfm#List).

[5] US Environmental Protection Agency, "Endocrine Disruptor Screening Program (EDSP)," Office of Chemical Safety and Pollution Prevention, updated November 25, 2014 (www.epa.gov/endo/). The list numbers 176 pages in length and includes both common substances such as aspirin, caffeine, cocoa butter, honey and onions, as well as complex chemical compounds.

[6] Brian Bienkowski, "New Report: Unregulated Contaminants Common in Drinking Water," *Environmental Health News* (December 5, 2013, available at www.environmentalhealthnews.org/ehs/news/2013/unregulated-water-contaminants). The article reports on research by scientists in the US Geological Survey and the EPA who found 11 perfluorinated compounds, an herbicide, two solvents, caffeine, an antibacterial compound, a metal and an antidepressant in samples obtained from 25 water utilities.

[7] For further discussion of these water treatment methods, see: EPA, Office of Water, "Drinking Water Treatment" (EPA 816-F-04-034, June 2004, available at www.epa.gov/ogwdw/sdwa/pdfs/fs_30ann_treatment_web.pdf); and Centers for Disease Control and Prevention, Healthy Water Program, "Water Treatment" (www.cdc.gov/healthywater/drinking/public/water_treatment.html).

stages. Coagulation, flocculation, and sedimentation are processes designed to clump small particles together into larger particles that will settle out of the water for removal. Filtration through sand, gravel, and charcoal addresses remaining many contaminants, such as particles of dust, parasites, bacteria, viruses, and chemicals. Disinfection is the final stage in most drinking water treatment systems. A disinfectant such as chlorine is typically added to kill any remaining microbes. Some water treatment systems use alternative disinfecting procedures, such as injecting ozone[8] and use of ultraviolet light[9]. While these alternatives have been found effective in eliminating a variety of biological contaminants, they do not inhibit or prevent regrowth of contaminants. Because of this possibility, chlorine is often used as a secondary treatment. Although costly, additional processes are often needed to address issues arising with the treatment of particular water sources, such as salinity, hardness, and chemical contamination.



Source: www.denverwater.org/your-water/treatment-process

Municipal Wastewater Treatment

The Clean Water Act controls the release of pollutants into waterways through a permitting process. All discrete point sources of discharges into surface water (or every pipe releasing treated water back into the water system) are required to obtain a discharge permit under the National Pollution Discharge Elimination System (NPDES). Municipal wastewater treatment plants that collect and treat household, commercial, and industrial sewage must obtain these permits. Permits are required for industrial wastewater sources that discharge directly into surface waters. Permits vary depending on type of pollutant, type of discharger (such as direct industrial discharger or municipal sewage system discharger), and nature of the local watershed.

[8] Brian Oram, "Ozonation in Water Treatment," Water Research Center, accessed 2015 (www.water-research.net/index.php/ozonation).

[9] Edstrom Industries, overview of ultraviolet energy applications in water sanitation, accessed 2014 (www.water-research.net/Waterlibrary/privatewell/UVradiation.pdf).

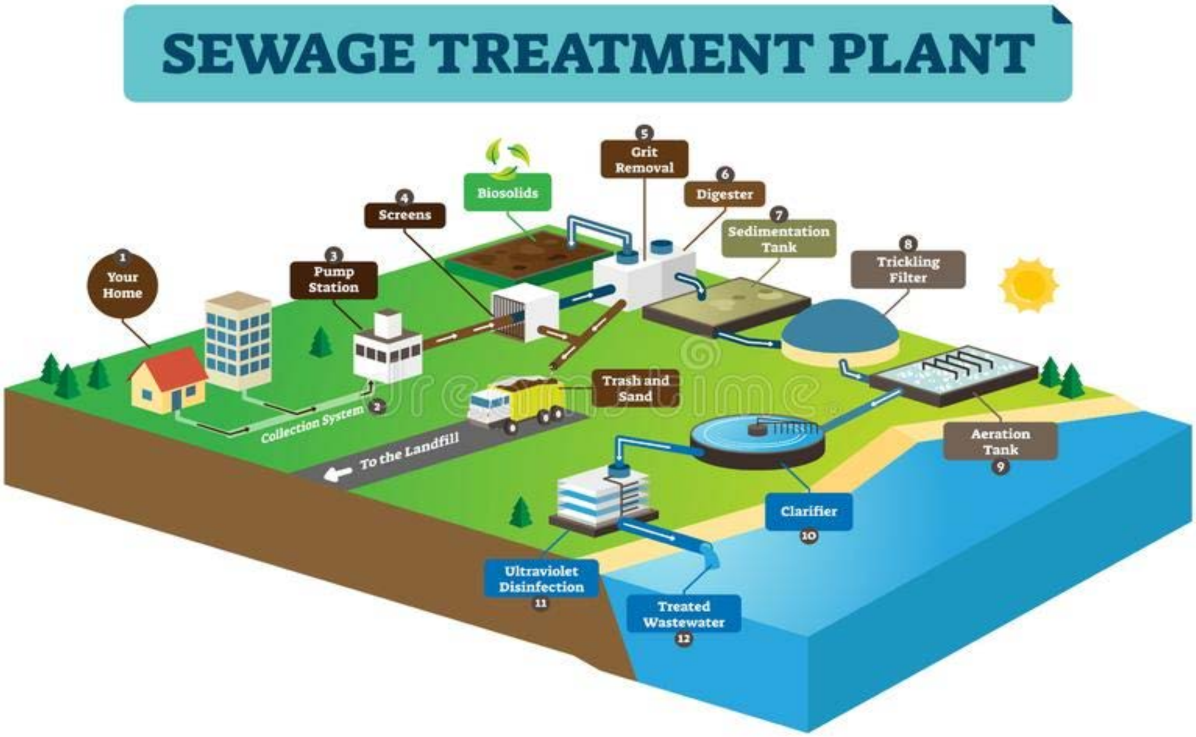
The NPDES permit program, managed by the EPA in partnership with state environmental agencies, regulates more than 400,000 sources nationwide.[10]

Wastewater treatment plants are located near rivers or shorelines to facilitate discharge of effluent, or treated wastewater, back to the water system. If discharged into the same source of water from which drinking water is drawn, then it is located downstream or some distance from the intake. Like drinking water, municipal wastewater moves through several treatment stages. Primary sewage treatment uses mechanical methods to remove solids and greases from the wastewater. Secondary treatment involves biological degradation of waste, using aeration and microbes to consume organic matter. Tertiary treatment applies chemical and other methods to complete the process, including use of disinfectants and steps targeted at removal of specific contaminants. After completing these steps, the effluent is released back into the water system.

Municipal Wastewater Treatment

Primary sewage treatment focuses on separating solid waste matter from the wastewater, using bar screens, grit chambers, settling tanks and removal of biosolids. Secondary treatment aerates the remaining wastewater and removes suspended and dissolved biological matter. Common options include use of trickling filters, activated sludge processes, and aerated lagoons to promote biological oxidation of wastewater. Tertiary wastewater treatment prepares the effluent for discharge back into the receiving water body with disinfection. Both chlorine and ultraviolet lights are commonly used to kill any pathogens that remain in the water. Source: Renewable Water Resources, 2018.

[10] US Environmental Protection Agency, Office of Water, "A Strategic Plan, 2001, FY 2001 and Beyond, Protecting the Nation's Waters Through Effective NPDES Permits" (EPA-833-R-01-001, available at www.epa.gov/npdes/pubs/strategicplan.pdf).



Source: www.dreamstime.com/illustration/wastewater-treatment-plant.html

<u>Pollutants in Municipal Wastewater</u>

Each wastewater treatment system obtains its own permit outlining plans for treating the particular set of pollutants present in the wastewater so that even with the discharge the receiving water body meets the state water quality criteria and standards and designated uses for that water body. Designated uses include public water supplies (requiring application of highest water quality standards for the protection and propagation of fish, shellfish, and wildlife), recreation, agriculture, industry, navigation, and some downstream uses.[11] The EPA identifies several sets of pollutants that municipal wastewater facilities target for control to meet state standards and designated beneficial uses.[12]

(1) Oxygen-Demanding Substances. Pollutants in wastewater place demands on the natural supply of dissolved oxygen in the water. Biochemical oxygen demand (BOD) is a measure of oxygen required for aquatic microorganisms to break down organic compounds in water. If effluent has high levels of organic pollutants or ammonia, it will use up more oxygen from the water and leave less for fish and other aquatic species.

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[11] US Environmental Protection Agency, "Water Quality Standards Handbook - Chapter 2: Designation of Uses (40 CFR 131.10)," Office of Water, updated November 20, 2014 (water.epa.gov/scitech/swguidance/standards/handbook/chapter02.cfm).

[12] US Environmental Protection Agency, "Primer for Municipal Wastewater Treatment Systems," Office of Water and Office of Wastewater Management (EPA 832-R-04-001, September 2004): 8 (water.epa.gov/aboutow/owm/upload/2005_08_19_primer.pdf).

(2) Pathogens. Infectious microorganisms can move from wastewater to the water system. Disease-causing organisms originate from municipal sewage sources, as well as industrial wastes, such as from meat packing plants. They also might enter surface water by way of storm runoff with animal waste from pets, livestock, and wild animals. Humans may come in contact with these pathogens either by drinking contaminated water or through swimming, fishing, or other contact activities. Modern disinfection techniques have greatly reduced the danger of waterborne disease.

Algal bloom in Lake Erie from excess nutrients, as seen from NASA's Aqua satellite, September 26, 2013. The bloom is *microcystis,* a form of blue-green algae which causes liver toxins. Source: NASA Earth Observatory, 2019.

(3) Nutrients. Carbon, nitrogen and phosphorus are chemical elements central to ecological nutrient cycling and essential to the production of living matter. These are naturally present in water, but are often present in large amounts from detergents, other types of sewage, and in runoff from fertilized land. Excess amounts of these nutrients overstimulate the growth of aquatic plants, including algal blooms. Uncontrolled algae growth blocks sunlight and can lead to the creation of dead zones from eutrophication (i.e., depletion of oxygen in the water). Extreme cases of nutrient overload can result in dead zones, or hypoxic (low oxygen) regions in rivers, lakes and coastal waters where animal life suffocates and dies.

(4) Inorganic and Synthetic Organic Chemicals. As the EPA notes, this category of pollutants includes a vast array of chemicals.[13] Many of these types of chemicals originate with common consumer items including detergents, household cleaning products, pharmaceuticals and personal care products, synthetic pesticides and herbicides, and the chemicals and wastes produced by industry in the manufacture of these products. Some of these appear on the EPA's Clean Water Act list of 126 priority chemicals (heavy metals and organic compounds), defined as toxic pollutants for which analytical test methods and control technologies exist.[14] None of the chemicals of concern introduced in this handbook appear on the EPA's priority chemicals list.

[13] Ibid.

[14] US Environmental Protection Agency, "Priority Pollutants," Office of Water, Clean Water Act Methods, updated December 3, 2014 (water.epa.gov/scitech/methods/cwa/pollutants.cfm).

(5) Thermal Heat. Higher water temperatures reduce the capacity of water to retain dissolved oxygen. Water used for cooling processes in power plants and some industries is discharged at elevated temperatures into receiving water. Discharges from wastewater treatment plants and stormwater retention ponds can be released at temperatures above those of receiving water, particularly in the heat of summer. Waste heat can substantially alter aquatic ecology by disrupting aquatic communities and potentially killing certain species.

> **Wastewater Treatment Objectives**
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> **Maintain water quality of natural water bodies – lakes, rivers, streams**
> **Prevent contamination of drinking water**
> **Allow for recreational uses, including fishing and swimming**
> **Protect aquatic life and ecosystems**

Chemicals of concern covered in this handbook are not routinely monitored, measured or treated in municipal wastewater treatment processes. It is possible that some of the current wastewater treatment measures remove some portion of these additional unregulated contaminants. However, the fact that chemicals of concern are found downriver from wastewater treatment plants demonstrates that standard treatment processes are not capturing all of them.[15]

Exemptions from Wastewater Treatment Requirements: Nonpoint Source Pollution

The Clean Water Act focuses regulatory effort on water that is discharged from "point sources," or "any discernible, confined and discrete conveyance"[16] such as the pipes carrying municipal or industrial sewage or identifiable waste channels. Nonpoint source pollution is not subject to these same rules. Nonpoint source pollution comes from diffuse sources that are not channeled into a receiving stream from a pipe or other discrete source. As EPA notes, "States report that nonpoint source pollution is the leading remaining cause of water quality problems… [W]e know that these pollutants have harmful effects on drinking water supplies, recreation, fisheries and wildlife."[17]

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[15] See, for example, discussion of a recent study tracking chemicals found in flame retardants from household dust to laundry wastewater, and then to the aquatic environment following wastewater treatment: Erika D. Schreder and Mark J. La Guardia, "Flame Retardant Transfers from U.S. Households (Dust and Laundry Wastewater) to the Aquatic Environment," *Environmental Science & Technology* 48, issue 19 (October 7, 2014): 11575-11583 (pubs.acs.org/doi/abs/10.1021/es502227h). See also the findings regarding variable removal rates of pharmaceuticals and personal care products in sewage treatment: Suarez, Sonia, M. Caraballa, F. Omil, and J.M. Lema, "How are pharmaceutical and personal care products (PPCPs) removed from urban wastewaters?" *Reviews in Environmental Science and Biotechnology* 7 (2008):125-138.

[16] Clean Water Act, Section 502(14), "General Definitions," updated March 6, 2012 (water.epa.gov/lawsregs/guidance/wetlands/sec502.cfm).

[17] US Environmental Protection Agency, "What is Nonpoint Source Pollution?" updated August 27, 2012 (water.epa.gov/polwaste/nps/whatis.cfm).

Households contribute to two of these nonpoint sources of water pollution: septic systems and runoff.

Point Source and Nonpoint Source Water Pollution

Point sources of wastewater are discharged through discrete, confined conveyances, typically pipes. Nonpoint sources are diffuse, coming in the form of surface runoff discharging to a water body, or moving through groundwater, such as from septic treatment systems.

Source: Purdue University Cooperative Extension

Wastewater from Septic Systems

For households connected into a municipal wastewater system, all drainpipes lead to the municipal wastewater treatment plant. Most US households are served by these centralized municipal wastewater systems. However, approximately one quarter of US households are served by individual onsite septic systems or small community cluster systems to treat their wastewater.[18] States, tribes, and local governments regulate septic and small community cluster systems while the EPA role is limited to providing voluntary guidelines and technical assistance.

Septic systems are well designed to treat natural human waste. As waste flows into the tank, heavier solids sink to the bottom, forming a sludge layer that is naturally decomposed by bacteria. Lighter substances, such as oils and small food particles, form a scum layer on the top. The bulk of the liquid waste resides in the middle of the receiving tank, which then moves on to the effluent drain field (or leach field) eventually draining through the soil absorption field on its way to the groundwater below. The bacterial treatment process breaks down human biological waste. Effluent draining from the system percolates through the soil, which provides some additional treatment benefits. Soil microorganisms further degrade the partially treated effluent, while remaining solids and other compounds adhere to soil particles.

Chemicals from personal care and household products are not eliminated in septic treatment systems. It is commonly assumed that dilution in the septic tank minimizes the potential of harmful effects.[19] However, negative human health and environmental consequences have been found in association with trace levels of many of these chemicals which means that even here dilution does not solve the problem of pollution. In higher concentrations, these chemicals can inhibit or destroy

Household Chemicals in Septic Wastewater

Septic systems do not treat chemicals in wastewater. Chemicals from household products can leach with effluent that drains into groundwater. Chemicals also flow into surface water, particularly when soil is saturated or the septic system is located near a lake or river.
Source: Cornell Cooperative Extension

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[18] US Environmental Protection Agency, Office of Water, "Septic (Onsite/Decentralized) Systems," Water Infrastructure, last updated December 12, 2014 (water.epa.gov/infrastructure/septic/).

[19] John J. Schwartz, Ann T. Lemley and Kalpana Pratap, "Household Chemicals and Your Septic System," Water Treatment NOTES, Fact Sheet 16, Cornell Cooperative Extension, College of Human Ecology, December 16, 2004 (waterquality.cce.cornell.edu/publications/CCEWQ-16-HouseholdChemicalsSeptic.pdf).

the septic bacteria and soil microorganisms needed to break down wastewater, and can contaminate groundwater.[20]

While groundwater and surface water are often viewed as separate water systems, they are connected through the soil. Where the groundwater table is high or the receiving soils are saturated, groundwater is released to the surface where it joins other runoff. Water originating from septic effluent is also transported by groundwater flow through lake-bottom sediments into lake water, bringing along contaminants such as nutrients and chemicals.[21] Controlling for dispersed leakages from septic systems is a major engineering problem in need of a solution.

Household Runoff

Runoff is precipitation that does not soak into the ground where it falls. It comprises one of the largest sources of water pollution in the US. Water coming from rainfall, snowmelt, irrigation or the garden hose runs over land, picking up pollutants along the way, and taking them to the water system. Agricultural operations account for a major portion of runoff pollution, as plowed soil is exposed and vulnerable to erosion under irrigation or rainwater, taking fertilizer and pesticides along with soil to the water system. Urban and suburban communities contribute many other contaminants to runoff as water washes off parking lots, roads and lawns. Stormwater can pick up dirt, debris, chemicals, and other pollutants and take these to a storm sewer system or directly to a body of water. Because the sources are diffuse with every lakeshore, riverbank, and stream channel providing access points, control of runoff poses major challenges to environmental protection efforts.

The Clean Water Act was amended in 1987 to increase regulation of stormwater runoff, requiring states to regulate municipal storm sewer systems as point sources, as well as certain other construction and industrial activities from which pollutants might be discharged under stormwater overflow conditions. The same amendments directed states to develop and implement "voluntary nonpoint pollution management programs."[22] However, most runoff continues to find its way to the water system without undergoing any treatment.

Homes and gardens add a variety of pollutants to runoff. Herbicides, insecticides, fertilizers and other contaminants found in garden care products are easily swept away in runoff. Runoff can transport contaminants leaching from the garden hose and other garden tools to the water system without undergoing any treatment. Household runoff can move the chemicals found in outdoor cleaning products; viruses, bacteria and nutrients from pet waste; oil and grease from motor vehicles; and heavy metals from roof shingles and other sources. Once the runoff leaves the

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[20] Ibid.

[21] Whitefish Lake Institute, "Investigation of Septic Leachate to the Shoreline Area of Whitefish Lake, Montana, Final Report" (RRG-11-1474), prepared for Whitefish County Water District, March 1, 2012 (www.lagrangecountyhealth.com/Documents/SepticLeachateFinal2.pdf).

[22] The 1987 Clean Water Act Amendments established the Section 319 Nonpoint Source Management Program to focus state and local efforts on addressing nonpoint source pollution, but does not mandate any treatment. Section 319 makes grants available for education, training, technology transfer, demonstration projects and monitoring to assess the success of specific nonpoint source implementation projects. See the US EPA's "Stormwater Basic Information" for additional information on stormwater regulatory requirements (water.epa.gov/polwaste/npdes/stormwater/Stormwater-Basic-Information.cfm).

home garden, it typically transfers to paved surfaces such as asphalt and concrete, which do not allow the water to soak into the ground and which contain additional pollutants. Household runoff can result in major harm to fish and other wildlife, the drinking water supply, and the rivers and lakes where people enjoy recreation and access to nature.

Advanced Treatment Technologies for Contaminants of Emerging Concern

Unregulated contaminants of concern in the water system are not regularly monitored, measured or targeted for treatment. However, those responsible for protecting water quality are paying attention to the growing research record on chemicals of concern. New contaminant removal strategies are being tested in both drinking water and wastewater treatment systems.

The EPA has compiled and reviewed the results of numerous studies on wastewater treatment technologies and their effectiveness in addressing chemical contaminants of emerging concern.[23] In presenting its findings, the EPA was careful to note that the data was being provided for information purposes only, asserting that "Wastewater treatment plant operators, designers, and others may find this information useful in their studies of ways to remove CECs from wastewater. In this report, EPA is not promoting any one technology nor is EPA setting Agency policy or priorities in terms of risk."[24] Advanced treatment methods to remove micro pollutants include both removal and transformation processes.

Removal technologies include physical barriers and adsorption to extract the targeted contaminants from water. Nanofiltration membranes control for pore size, filtering out larger contaminant particles while allowing liquid and smaller particles to pass through. Reverse osmosis is a related technology, which uses pressure or a vacuum to drive water through a membrane while leaving contaminants behind. Removal can be achieved through adsorption processes, the binding of molecules or particles to a surface. Granular activated carbon adsorption (applied in granular or powdered form) is used in water treatment to remove dissolved materials from solution.

Transformation methods involve the introduction of a substance into the water for the purpose of transforming contaminants into less harmful chemical constituents. Chlorine disinfection is an example of a transformation method commonly used to inactivate pathogens in water. However, in addition to inactivating microbes, chlorine can transform organic chemicals, which sometimes generates chloroform and other potentially harmful disinfection byproducts. For chemicals of concern, other transformation methods are being applied. Activated sludge is the most common type of secondary treatment used in municipal wastewater treatment plants.[25] This two-stage suspended growth biological treatment process has been used to treat contaminants of concern

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[23] US Environmental Protection Agency, National Service Center for Environmental Publications (NSCEP), "Treating Contaminants of Emerging Concern: A Literature Review Database" (August 2010, EPA-820-R-10-002), p. 1, available at nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1008IK3.TXT. The EPA specifically examined 88 research studies that presented analytical data for 596 different treatment systems focused on "the removal of CECs from water and wastewater by both commonly used and innovative treatment technologies." See Appendix C of the EPA report for an annotated bibliography of studies evaluating the application of these various treatment options.

[24] Ibid.

[25] Ibid.

through biodegradation and/or adsorption to the solid material wasted from the system. Ultraviolet light reacts with organic molecules. It is used to inactivate microbes in water and has been used to transform contaminants of concern in some water treatment systems. Ozonation is a process that attacks and transforms contaminants through an oxidizing action from introduced ozone.

These advanced treatment methods have yielded mixed results in water treatment applications, reducing levels of some contaminants while having no effect on others.[26] One study based on measurements before and after adoption of an activated sludge system found some measurable positive effects on reducing endocrine-disrupting substances in the local water system.[27] The wastewater treatment upgrades followed analysis of endocrine-disrupting substances in the local water system. The City of Boulder, CO collaborated with the USGS and the University of Colorado in a 2007-08 fish feminization study comparing sex ratios of white suckers in Boulder Creek above and below the city's wastewater treatment facility. The results of that study found elevated levels of several estrogenic compounds in Boulder wastewater effluent (including natural and synthetic estrogens, nonylphenol and bisphenol A). These increased estrogen levels were associated with fish ratios heavily skewed to predominantly female and increased incidence of abnormal reproductive organs. Stream levels of estrogenic compounds below the wastewater treatment facility were decreased following adoption of the activated sludge treatment process. It is not yet clear what effect the upgraded treatment methods will have on stream ecosystems, but monitoring of fish effects continues.[28]

Though wastewater treatment facilities are not designed specifically to remove unregulated chemicals of concern, some chemicals of concern can be removed through secondary and other advanced treatments. The levels of removal vary depending on the type of contaminant and the processes used[29]. Additional research would be useful. Cost is the biggest limit to further development and application of new treatment methods specifically targeted at chemicals of concern. New treatment technologies are expensive to install, particularly when it involves

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[26] Ibid. The EPA reports removal rates of 16 selected analytes (including BPA, DEET, nonylphenol and triclosan) for each of the removal and transformation methods under review.

[27] Larry B. Barber, Alan M. Vajda, Chris Douville, David O. Norris and Jeffery H. Writer, "Fish Endocrine Disruption Responses to a Major Wastewater Treatment Facility Upgrade," *Environmental Science & Technology* 46, 4 (February 2, 2012): 2121-2131 (pubs.acs.org/doi/abs/10.1021/es202880e).

[28] US Geological Survey, "Improvements in Wastewater Treatment Reduces Endocrine Disruption in Fish," Environmental Health – Toxic Substances, updated December 19, 2014 (toxics.usgs.gov/highlights/boulder_wwpt/index.html).

[29] See, for example, the work of Petrović, Gonzalez and Barceló, who studied the effectiveness of several water treatment methods (including through standard activated sludge treatment as well as more advanced membrane processes and oxidation methods) for removal of chemicals of concern. The results showed that while some unregulated contaminants of concern were removed during wastewater and drinking water treatment, the currently achieved removal levels are not satisfactory. Mira Petrović, Susana Gonzalez, Damià Barceló, "Analysis and Removal of Emerging Contaminants in Wastewater and Drinking Water," first published in *Trends in Analytical Chemistry* Vol. 22, Issue 10 (Nov. 2003, digital.csic.es/bitstream/10261/20017/3/Petrovic_Mira_et_al.pdf).

retrofitting and adapting existing systems. They are also expensive to operate. Municipal water systems would have a hard time covering these costs.[30]

Water treatment systems focus on removal of specific contaminants from the water supply, which may not be enough for chemicals of concern. While existing water treatment facilities are designed to remove a wide range of organic and inorganic materials as well as pathogens, they do not address removal of most chemicals of concern. The concept of removal is a complicated one. In water treatment procedures, removal "simply means less of the target chemical was observed after treatment than before treatment… For many chemicals and treatment technologies, removal of a target chemical can be a removal from the water, including transfer to solids or transfer to air."[31] In other words, the chemicals do not disappear; they might simply be relocated. Removal might reflect chemical transformation to a different form, which might be of equal or greater concern than the parent contaminant.[32] For instance, there is concern in the scientific community that the degradation of some pharmaceuticals could lead to the release of estrogen as a by-product into our water supply. Chemical transfers and transformations resulting from water treatment may not, in fact, reduce the threats to human health and the environment. This emphasizes the importance for prevention of harmful chemicals at the source; this is where we can play a part.

Summary

Adoption of major legislation in the 1970s to address water quality concerns stands out as a major achievement in the US environmental protection record. However, chemicals of concern are not covered under these laws. They are not regularly monitored, measured or targeted for treatment. Even with the Safe Drinking Water Act, establishing water quality standards and processes for treating municipal drinking water supplies, contaminants of concern have been detected in treated drinking water. Furthermore, the CWA sets specific wastewater treatment standards that are designed to ensure that pollutants are removed from wastewater before being released back into rivers and lakes. These policies are in dire need of amendment to adapt to our increasingly changing and vulnerable social-ecological systems taking CECs into account. However, chemicals of concern are not among the pollutants that are specifically targeted for treatment, and many have been detected post-treatment. Furthermore, many chemicals of concern move through nonpoint source runoff, which is not subject to water treatment before entering the water system. New methods might remove some of these constituents, but removal through treatment does not eliminate the risks of toxic exposures to human health and the environment.

[30] See, for example, Stephan D. Frank, "A Balancing Act: Dealing with Infrastructure Needs," American Water Resources Association, *Water Resources Impact* Vol. 19, No. 3 (May 2007): 8-10.

[31] US Environmental Protection Agency, "Treating Contaminants of Emerging Concern: A Literature Review Database" (August 2010).

[32] Ibid.