



# Removal of Endocrine Disruptor Chemicals Using Drinking Water Treatment Processes



EPA/625/R-00/015  
March 2001

# **Removal of Endocrine Disruptor Chemicals Using Drinking Water Treatment Processes**

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## Foreword

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The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threatens human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and groundwater; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

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National Risk Management Research Laboratory

## **Abstract**

A group of chemicals, known as endocrine disruptor chemicals (EDCs), has been identified as having the potential to cause adverse health effects in humans and wildlife. Among this group, DDT, PCBs, endosulfan, methoxychlor, diethylphthalate, diethylhexylphthalate, and bisphenol A may occur in drinking water. The various components of the drinking water treatment process have been evaluated and granular activated carbon has been identified as the method to be used for the removal of EDCs from drinking water.

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## **Acknowledgments**

The Agency wishes to acknowledge Joanne Jackson of S.A.I.C., Inc., Reston, VA, who completed an extensive literature search needed for the preparation of this document as well as preparing the initial drafts of the text. The Agency also wishes to acknowledge the Science Team that prepared the "Risk Management Evaluation for Endocrine Disruptor Chemicals," a draft document that defines the risk management approach for dealing with this newly defined group of potential environmental pollutants. Lastly, the Agency wishes to acknowledge Thomas Speth who provided the engineering expertise needed to accurately describe the technological methods used in the removal of selected endocrine disruptor chemicals from drinking water and John L. Cicmanec who prepared the final text and provided the biological and chemical information needed for a basic understanding of the potential health and ecological effects of these substances.

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# Removal of Endocrine Disruptor Chemicals Using Drinking Water Treatment Processes

## I. Introduction

The purpose of this document is to provide a description of methods for the removal of endocrine disruptor chemicals (EDCs) from drinking water. Many of the potential EDCs may be present in surface waters or groundwaters. A number of drinking water treatment processes are available and may be used to remove many of the potential EDCs. This document presents treatment processes for large municipalities as well as small communities to remove specific EDCs from drinking water. References are provided with links to retrieve documents via the Internet, where available.

## II. Background

A growing body of scientific research indicates that man-made industrial chemicals and pesticides may interfere with the normal functioning of human and wildlife endocrine systems. A hormone is defined as any substance in the body that is produced by one organ then carried by the bloodstream to have an effect in another organ. The primary function of hormones, or the endocrine system, is to maintain a stable environment within the body; this is often referred to as homeostasis. The endocrine system also controls reproduction and growth. Recently, public concern has focused on the possible hormonal effects of some environmental pollutants on wildlife and humans. These chemicals, referred to collectively as endocrine disruptors, comprise a wide range of substances including pesticides (methoxychlor), surfactants (nonylphenol), plasticizers (diethylphthalate), and organohalogens (PCBs and dioxin). Many industrial chemicals and pesticides have undergone extensive toxicological testing; however, since the purpose of this testing was not to find some subtle endocrine effects these potential effects may not have been revealed. The persistence of some pesticides in the aquatic environment may pose a threat to the human population, especially if such substances occur in the nation's drink-



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ing water sources. As a result of this growing concern, the 1996 Safe Drinking Water Act (SDWA) Amendments and the Food Quality Protection Act require EPA to develop a screening and testing program to determine which chemical substances have possible endocrine disrupting effects in humans.

### **A. *Endocrine Disruptor Chemicals***

The term “endocrine disruptors” is used to describe substances that are not produced in the body but act by mimicking or antagonizing natural hormones. It is thought that EDCs may be responsible for some reproductive problems in both women and men as well as for the increases in the frequency of certain types of cancer. EDCs have also been linked to developmental deficiencies and learning disabilities in children. Because hormone receptor systems are similar in humans and animals, effects observed in wildlife species raise concerns of potential human health effects. During fetal development and early childhood, low-dose exposure to EDCs may have profound effects not observed in adults such as reduced mental capacity and genital malformations. Evaluating potential low-dose effects of environmental estrogenic compounds has been identified as a major research priority.

## **III. Descriptions of Specific EDCs**

In this section, the potential EDCs are grouped by chemical class. Descriptions of the EDCs provide the Chemical Abstract Registry Number, a brief description of the chemical, its major uses, the major human exposure routes, health effects, water solubility, environmental persistence, occurrence/detection in water sources, drinking water standards, and statutes that regulate the substance in water. The best available technology (BAT) as determined by laboratory testing for removal of specific EDCs from water is indicated when this has been determined. In this document the term “BAT” is NOT used in a regulatory context. That is to say, we do not intend to suggest that the reader is obligated to use a particular technology as a regulatory requirement.

### **A. *Pesticide Residues***

A number of pesticides have been implicated as endocrine disruptors, primarily in aquatic and wildlife species. Agricultural runoff is responsible for the presence of most pesticides found in surface waters. The pesticide concentrations in surface waters tend to be highest after the first storm following application. Pesticides may also enter source water from accidental spills, in wastewater discharges, or as runoff from urban and suburban areas. Because pesticides are known to be potentially highly toxic

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compounds, the maximum contaminant level (MCL) has been established for each of these substances. These limits were originally established on the basis of known toxicologic effects; however, in the future the MCLs may be set at even lower concentrations if adverse endocrine effects are detected due to their presence. Again, this document does not infer that the reader is obligated to attain an MCL, rather this information is presented to demonstrate how future research on EDCs may eventually impact some MCLs.

## **DDT**

DDT [CASRN - 50-29-3] is an organochlorine insecticide used mainly to control mosquito-borne malaria. It is the common name of the technical product that is a mixture of three isomers of DDT and contains 65 to 80% p,p'-DDT. It is very soluble in fats and most organic solvents and practically insoluble in water. In the U.S., DDT is currently used only for public health emergencies as an insecticide under Public Health Service supervision and by the USDA or military for health quarantine. EPA banned use of DDT in food in 1972 and use in nonfoods in 1988. At present no U.S. companies are producing DDT. The primary supporting evidence for adverse health effects in humans comes from an epidemiological study performed by Rogan in North Carolina in which blood levels of DDE (a metabolite of DDT) were determined in pregnant women. Once the blood levels were determined for each woman, neurologic testing was then performed on the infants that were born from these pregnancies. A very strong correlation was found linking increased blood levels of DDE with poor performance of the neurologic tests by these infants (Rogan, 1986). Strong correlation of maternal serum levels of DDE, a metabolite of DDT, with defects in muscular tone and hyporeflexia was observed in their children. More convincing evidence of endocrine effects has been observed in an ecological setting. The initial reports were of egg shell thinning in bald eagles as well as vitellogenin (a protein that is normally only produced in the livers of female amphibians and fish) production in male African clawed frogs (Palmer and Palmer, 1995). Primary exposure routes for humans are inhalation, ingestion, and dermal contact.

In spite of the 1972 ban of DDT in the U.S., human exposure to DDT is potentially high due to its prior extensive use and the persistence of DDT and its metabolites in the environment. DDT has been detected in air, rain, soil, water, animal and plant tissues, food, and the work environment. Break-down products in the soil environment are DDE and DDD, which are also highly persistent. Due to its extremely low solubility in water, DDT is mainly retained by soils and soil fractions with higher proportions of soil organic matter. While it is generally immobile or only very slightly mobile, DDT may

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leach into groundwater over long periods of time. DDT may reach surface waters primarily by runoff, atmospheric transport, drift, or by direct application. DDT has been widely detected in ambient surface water sampling in the U.S. at a median level of one nanogram/L (part per trillion). DDT is regulated by EPA under the Clean Water Act (CWA). Effluent discharge guidelines and water quality criteria have been set under the CWA.

## **Endosulfan**

Endosulfan [CASRN - 115-29-7] is a chlorinated hydrocarbon insecticide which acts as a poison for a wide variety of insects and mites on contact. Although it may be used as a wood preservative, it is used primarily on a wide variety of food crops, including tea, coffee, fruits, and vegetables, as well as on rice, cereals, maize, sorghum, or other grains. Human exposure to endosulfan is primarily through breathing air, drinking water, eating food, or working where endosulfan is used. Exposure to endosulfan mainly affects the central nervous system. The effects of long-term/low-dose exposure are unknown. The most convincing evidence of endocrine effects in mammals is taken from laboratory animal studies in which doses of 5 mg/kg/day resulted in reduced sperm counts and altered testicular enzyme levels in male rats (Sinha, 1995).

Endosulfan has been found in at least 143 of the 1,416 National Priorities List sites identified by the EPA. Although not easily dissolved in water, when released to water, endosulfan isomers hydrolyze readily in alkaline conditions and more slowly in acidic conditions. Endosulfan has been detected at levels of 0.2 to 0.8 µg/L in groundwater, surface water, rain, snow, and sediment samples. Large amounts of endosulfan can be found in surface water near areas of application. The EPA recommends that the amount of endosulfan in lakes, rivers, and streams should not be more than 74 ppb. Humans can become exposed to endosulfan by drinking water contaminated with it.

## **Methoxychlor**

Methoxychlor [CASRN - 72-43-5] is an organochlorine insecticide that is effective against a wide range of pests encountered in agriculture, households, and ornamental plants. It is registered for use on fruits, vegetables, and forage crops. The use of methoxychlor has increased significantly since DDT was banned in 1972. It is similar in structure to DDT, but it has a relatively low toxicity and relatively low persistence in biological systems. Methoxychlor is not highly soluble in water. Methoxychlor is highly toxic to fish and aquatic invertebrates. Levels of methoxychlor can accumulate in algae, bacteria, snails, clams, and some fish, but it is usually transformed into other substances and rapidly released from their bodies. The most

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probable routes of exposure for humans are inhalation or dermal contact during home use, and ingestion of food or drinking water contaminated with methoxychlor. Short-term exposure above the MCL causes central nervous system depression, diarrhea, and damage to liver, kidney, and heart tissue. Evidence suggests that high doses of technical methoxychlor or its metabolites may have estrogenic effects.

The risk of human exposure via groundwater should be slight, but it may be greater if application rates are very high, or if the water table is very shallow. At present the strongest evidence of endocrine effects due to methoxychlor is taken from laboratory studies in which the relatively low dose of 0.5 µg/kg/day caused reduced fertility in mice (Welch, 1969).

In an EPA pilot groundwater survey, methoxychlor was found in a number of wells in New Jersey and at extremely low concentrations in water from the Niagara River, the James River, and an unnamed Lake Michigan tributary. Methoxychlor will most likely reach surface waters via runoff. Methoxychlor was detected in drinking water supplies in rural South Carolina. EPA set a limit of methoxychlor in drinking water at 0.04 ppm. EPA advises that children should not drink water containing more than 0.05 ppm for more than one day and that adults should not drink water containing more than 0.2 ppm for longer periods of time.

## ***B. Highly Chlorinated Compounds***

### **Polychlorinated Biphenyls (PCBs)**

Polychlorinated biphenyls [CASRN - 1336-36-3] are a group of manufactured organic compounds that include 209 different chemical forms known as congeners. This high number of many different chemical forms is possible because from one to ten chlorine atoms can attach to the carbon atoms that make up the basic chemical structure of this family of compounds. PCBs are thermally stable, resistant to oxidation, acids, bases, and other chemical agents. PCBs tend to be more soluble in lipid-based solvents than in water; however, among the 209 congeners there is a wide range of water solubility and lipid solubility with the lesser chlorinated congeners being more water soluble. In the environment, PCBs can be contaminated with dibenzofurans, dioxins, and polychlorinated naphthalenes. Since 1974, all PCB manufacturing has been banned and previous use in electrical capacitors and transformers has been greatly reduced. Because of their chemical-resistant properties, PCBs have persisted in the environ-

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ment in large quantities despite the manufacturing ban. The primary routes of potential human exposure to PCBs are ingestion of food and water as well as through dermal contact. There is extensive human data which show a strong association of low birth weights and shortened gestation with PCB exposure in humans (Taylor, 1987 and Patandin, 1998). In addition, extensive neurologic testing of children who experienced exposure to PCBs prior to birth revealed impaired motor function and learning disorders (Jacobsen, 1996). Studies have indicated that PCBs concentrate in human breast milk.

PCB releases from prior industrial uses and the persistence of the compounds in the environment have resulted in widespread water and soil contamination. They have been found in at least 383 of the 1,430 National Priorities List sites identified by the EPA. The PCBs with a high degree of chlorination are resistant to biodegradation and appear to be degraded very slowly in the environment. PCB concentrations in water are higher for the lower chlorinated PCBs because of their greater water solubility. PCBs have been found in runoff, sediments, soil, creek water, leachate, in an underground oil-water layer, and in pond effluents. Concentrations in these locations have ranged from 4 to 440,000 µg/L. In water, small amounts of PCBs may remain dissolved, but most adhere to organic particles and sediments. PCBs in water bioaccumulate in fish and marine mammals and can reach levels several orders of magnitude higher than levels found in the water. EPA regulates PCBs under the CWA and has established water quality criteria and toxic pollutant effluent standards. Based on the carcinogenicity of PCBs, EPA published a MCL Goal for PCBs at zero and the MCL of 0.5 µg/L (0.5 ppb) under the SDWA.

### **Dioxin (2,3,7,8-tetrachlorodibenzo-p-dioxin TCDD)**

Dioxin is considered an EDC on the basis of its effects that occur during pregnancy which result in many malformations observed in the offspring of many species including humans. Dioxin [CASRN - 1746-01-6] is a contaminant formed during the manufacture of 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), an herbicidal compound that comprised about 50% of the defoliant Agent Orange, and 2,4,5-T derivatives, as well as other chemicals synthesized using 2,4,5-trichlorophenol. Dioxins may also be formed during incineration of chlorinated industrial compounds such as plastic and medical waste. Dioxin is one of the most acutely toxic compounds synthesized by modern chemistry. TCDD is the most toxic member of the 75 dioxins that exist and is the one most studied. It is almost insoluble in water. TCDD is stable in water, dimethylsulfoxide, 95% ethanol, or acetone. It can undergo a slow photochemical and bacterial degradation, though normally it is extremely stable. Dioxin is degraded when

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heated in excess of 500°C or when exposed to ultraviolet radiation under specific conditions. TCDD has no known commercial applications but is used as a research chemical. TCDD has been found in at least 91 of 1,467 National Priorities List sites identified by the EPA. Dioxins are widespread environmental contaminants. They bioaccumulate throughout the food web because of their lipophilic properties and slow metabolic destruction. The primary source of dioxin exposure to humans is from food.

## **Furan**

Furan [CASRN - 110-00-9] is classified as a cyclic, dienic ether; it is a colorless, flammable liquid. It is insoluble in water, but is soluble in alcohol, ether, and most common organic solvents. Furan is used primarily as an intermediate in the synthesis and production of other organic compounds, including agricultural chemicals (insecticides), stabilizers, and pharmaceuticals. The primary route of potential human exposure to furan is inhalation.

Furan was detected in 1 of 63 industrial effluents at a concentration of less than 10 µg/L. Furan was detected in a creek in the Niagara River watershed and in the Niagara River.

## **C. Alkylphenols and Alkylphenol Ethoxylates**

Nonylphenol (NP) [CASRN - 25154-52-3]/[84852-15-3] and octylphenol are the largest volume alkylphenol products manufactured in the U.S. Alkylphenols (APs) such as nonylphenol and octylphenol are mainly used to make alkylphenol ethoxylate (APE) surfactants. These surfactants are the primary active ingredients in industrial chemicals that are used as cleaning and sanitizing agents. Nonylphenol ethoxylates (NPE) account for approximately 80% of total APE use with total U.S. production exceeding 500 million pounds per year. Alkylphenols are also used as plasticizers, in the preparation of phenolic resins, polymers, heat stabilizers, antioxidants, and curing agents. APEs do not break down completely in sewage treatment plants or in the environment. The most widely used NPEs have nine- or ten-member carbon chains attached to the ethoxylate group. Thus, the great majority of NPEs in use are easily dissolved in water. Human exposure to APs and APEs may occur through contaminated drinking water that has been extracted from polluted waters. At present there is no conclusive evidence that APs or APEs cause adverse health effects in humans; however, there are many reports of alkylphenols causing production of a female-associated liver protein, vitellogenin, in male fish (Jobling, 1995).

Investigations of NP levels in rivers have found values varying between 2 µg/L in the Delaware River in Philadelphia to 1000 µg/L in the

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Rhine, and 1000 µg/L in a tributary of the Savannah River. Drinking water is frequently taken from rivers and can easily become contaminated with alkylphenols. Analysis of many drinking water samples in the U.S. has found an overall average concentration of alkylphenolic compounds of 1 µg/L. Studies in the U.S. show NPE removal from wastewater ranging from 92 to 99% with minor seasonal variations. NPE concentrations in discharges after treatment are reportedly low, varying between 50 and 200 ppb. Draft EPA water quality guidelines for nonylphenol in freshwater are 6.6 ppb water (four-day average) and 25 ppb (one-hour average), and in saltwater, they are 1.6 ppb (four-day average) and 6.2 ppb (one-day average).

#### ***D. Plastic Additives***

##### **Bisphenol A**

Bisphenol A [CASRN - 80-05-7] is an industrial chemical used to synthesize epoxy resins or polycarbonate plastic. Human exposure to the potential endocrine disrupting effects of bisphenol A may occur when this chemical leaches out of the plastic due to incomplete polymerization, or breakdown of the polymer upon heating. Polycarbonates are commonly used for food and drink packaging materials and infants are the subgroup of the population that is most highly exposed to this compound. Bisphenol A is also used in plastic dental fillings.

Bisphenol A is a solid which has low volatility at ambient temperatures. It has a water solubility of 120-300 mg/L. Its water solubility increases with alkaline pH values. Releases of bisphenol A into the environment are mainly in wastewater from plastics-producing industrial plants and from landfill sites that contain large quantities of plastics. Bisphenol A does not bioaccumulate in aquatic organisms to any appreciable extent. If released into acclimated water, bisphenol A would biodegrade. In untreated water, bisphenol A may biodegrade after a sufficient adaptation period, it may adsorb extensively to suspended solids and sediments, or it may break down upon exposure to light.

##### **Diethyl Phthalate (DEP)**

Diethyl Phthalate [CASRN - 84-66-2] is a synthetic substance that is commonly used to increase the flexibility of plastics used to make toothbrushes, automobile parts, tools, toys, and food packaging. It is also used in cosmetics, insecticides, and aspirin. DEP can be released fairly easily from these products since it is not part of the polymer. Plastic materials containing DEP in waste disposal sites constitute the major reservoir of DEP in the environment. If released to water, DEP is expected to undergo aerobic biodegradation. Humans are exposed to DEP through consumer

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products and plastics, contaminated air, or contaminated drinking water and foods.

There is evidence which shows a strong correlation with impaired reproductive performance in multigeneration studies in rodents (Wine, 1997); however, endocrine effects associated with DEP exposure in humans have not been reported.

DEP has accumulated and persisted in the sediments of the Chesapeake Bay for over a century. DEP has been detected in surface water samples from Lake Ponchartrain and the lower Tennessee River, as well as other industrial river basins. Surface water samples collected along the length of the Mississippi River contained DEP in significant concentrations. DEP has been detected in groundwater in New York State public water system wells, near a solid waste landfill site in Norman, OK, and at sites in Fort Devens, MA, Boulder, CO, Lubbock, TX, and Phoenix, AZ. DEP has been identified in drinking water in the following cities: Miami, Philadelphia, Seattle, Lawrence, New York City, and New Orleans.

### **Di(2-ethylhexyl) Phthalate (DEHP)**

Di(2-ethylhexyl) Phthalate [CASRN - 117-81-7] is a manufactured chemical that is used primarily as one of several plasticizers in polyvinyl chloride (PVC) resins that make plastics more flexible. It is the most commonly used of a group of related chemicals called phthalates or phthalic acid esters. DEHP is also used in inks, pesticides, cosmetics, and vacuum pump oil. DEHP is everywhere in the environment because of its use in plastics in large quantities, but it evaporates into air and dissolves in water at very low rates. The primary routes of potential human exposure to DEHP are inhalation, ingestion, and dermal contact in occupational settings and from air, from consumption of drinking water, food, and food wrapped in PVC. It is easily dissolved in body fluids such as saliva and plasma. DEHP is biodegradable, but it tends to partition into sediment where it is relatively persistent. It also tends to bioconcentrate in aquatic organisms. Because of its low vapor pressure, human exposure to DEHP in either water or air appears to be minimal.

DEHP has been detected frequently in surface water, groundwater, and finished drinking water in the U.S. at concentrations in the low ppb range. Groundwater in the vicinity of hazardous waste sites may be contaminated with DEHP. EPA regulates DEHP under the CWA and the SDWAA. DEHP is included on lists of chemicals for which water quality criteria have been established under the CWA. EPA classifies DEHP as a water priority pollutant and has set the MCL Goal at zero. EPA has set the MCL at six parts DEHP per billion parts of drinking water (six ppb).



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## **IV. Water Treatments for EDC Removal**

Water suppliers use a variety of treatment processes to remove contaminants from drinking water. Individual processes may be arranged as series of processes applied in a sequence. Water utilities select a treatment train that is most appropriate for the contaminants found in the source water. The most commonly used processes include flocculation, sedimentation, filtration, and disinfection for surface water. Some treatment trains also include ion exchange and adsorption. These conventional processes are inefficient for substantially reducing certain pesticide concentrations and other EDCs.

The processes described later in this section can be used for removal of EDCs as specified, either individually or as a class of compounds. The feasibility of using the various techniques will depend on the size of the system and the cost effectiveness. The two major concerns regarding technologies for small systems are affordability and technical complexity (which determine the needed skills for the system operators).

### ***A. Water Treatment Techniques***

#### **Activated Carbon (Granular and Powdered)**

Activated carbon is similar to charcoal in composition, but its surface has been altered to enhance its sorption properties. Activated carbon is made from a variety of materials including wood, coal, peat, sawdust, bone, and petroleum distillates. For use in drinking water treatment plants activated carbon produced from wood and coal is most commonly used. The base carbon material is dehydrated then carbonized through slow heating in the absence of air. It is then activated by oxidation at high temperatures (200 to 1000°C), resulting in a highly porous, high surface area per unit mass material. The activation process is considered a two-step procedure in which amorphous material is burned off and pore size is increased. Typically, GACs have surface areas ranging from 500 to 1400 square meters/gram.

GAC treatment removes contaminants via the physical and chemical process of sorption. The contaminants accumulate within the pores and the greatest efficiency is attained when the pore size is only slightly larger than the material being adsorbed. Removal efficiencies for many organic contaminants are good to excellent. Water quality parameters such as dissolved organic matter, pH, and temperature can significantly affect the removal efficiency of GAC. However, for GAC treatment of drinking water it is necessary to reduce the total organic carbon (TOC) of the treated water through the preliminary steps of coagulation/filtration before treat-

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ment with GAC. Its removal efficiencies change drastically once the bed nears exhaustion, as contaminant breakthrough occurs. GAC beds can be reactivated by removing the granular carbon from the water treatment chambers, drying the material then placing it in large furnaces that heat the material to 1200 to 1400°F. This heating process removes any residual of contaminants from the pores and again enlarges the pore size. This feature and the high temperatures needed to attain reactivation should be kept in mind when considering claims of some manufacturers that flushing point-of-use (POU) GAC filters with hot water will reactivate units or increase operating efficiency. The increased temperatures that are reached with hot water DO NOT in any manner achieve reactivation.

The performance of GAC for specific contaminants is determined in the laboratory by trial runs and is performed one chemical at a time. The following text is presented to provide the reader with a basic understanding of how the relative capacity of activated carbon to remove a chemical from water (a liquid phase) was determined. Data are gathered within a laboratory setting and determined on the basis of one chemical at a time. This document is not intended to equip the reader to perform laboratory-scale studies to derive values for specific compounds that may be of interest to them. The Freundlich equation can be used to indicate the efficiency of GAC/PAC treatment. The Freundlich equation is expressed as:

$$Q_e = K \times C_e^n$$

where  $Q_e$  is the equilibrium capacity of the carbon for the target compound, ( $\mu\text{g/g}$ ),  $C_e$  is the equilibrium liquid-phase concentration of the target compound ( $\mu\text{g/L}$ ), and  $K$  and  $1/n$  are the Freundlich coefficients in ( $\mu\text{g/g})(\text{L}/\mu\text{g})^{1/n}$  and dimension-less units, respectively. The  $K$  values that are determined for each chemical are a means of expressing the “ability” of a particular GAC to remove a chemical.

Typically when  $K$  values that are greater than 200 are attained the process is considered to be economically feasible. In addition, the process of GAC can be fine tuned, that is, certain basic parameters such as pH, temperature or choice of carbon source can be altered to increase efficiency of the process when certain critical contaminants such as pesticides must be removed.

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**Maintenance**--Careful monitoring and testing are required to ensure that all contaminants are removed. The carbon media must be replaced regularly. The replacement intervals depend on the type of contaminant, concentration, rate of water usage, and the type of carbon used in the system. There is potential for bacterial growth on the adsorbed organic chemicals; routine maintenance must be performed. When POU devices are used for compliance for small systems, programs for long-term operation, maintenance, and monitoring must be provided by the water utility.

Powdered activated carbon (PAC) also functions by adsorption of contaminants from water onto a solid phase material, in this case powdered carbon. PAC differs from GAC in that the powdered carbon is added to the water in a large tank, a period of time is provided for adsorption of the contaminants to occur, then the powdered carbon is later removed in a filtration process. This process also differs from GAC in that PAC needs to be added continually to the process; however, the process is less expensive and less technically demanding but it is more labor intensive. PAC is more adaptable to short-term applications rather than as a continual use process. For contaminants such as pesticides which are mostly used during a six-week period in late spring and summer, PAC may be a particularly useful choice. The water being treated comes into contact with much less carbon material per unit volume treated, so the process is not as efficient as GAC.

GAC is the BAT for removal of all of the selected EDCs that are discussed in this document. However, since other technologies are used in the multistep process of drinking water treatment, a brief discussion is included for those processes that enhance the performance of GAC.

### ***Coagulation/Filtration***

Coagulation/Filtration processes involve the addition of chemicals like iron salts, aluminum salts, with and without anionic, cationic, or anionic-cationic polymers that coagulate and destabilize particles suspended in the water. The suspended particles are ultimately removed via clarification and/or filtration. Conventional filtration includes pretreatment steps of chemical coagulation, rapid mixing, and flocculation, followed by floc removal via sedimentation or flotation. After clarification, the water is filtered using common filter media such as sand, dual-media, and tri-media. Direct filtration has several effective variations, but all include a pretreatment of chemical coagulation, followed by rapid mixing. The water is filtered through dual- or mixed-media using pressure or gravity filtration units.

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## ***Lime Softening***

In the lime-softening (LS) process, the pH of the water being treated is raised sufficiently to precipitate calcium carbonate and, if necessary, magnesium hydroxide to reduce water hardness. The chemical groups that contain most of the EDCs are not affected by LS.

## ***Point-of-Use/Point-of-Entry Treatments***

The SDWA identifies both point-of-entry (POE) and POU treatment units as options for compliance technologies for small systems. A POU treatment device treats only the water at a particular tap or faucet, resulting in other taps in the facility serving untreated water. POU devices are typically installed at the kitchen tap. POU devices are listed as compliance technologies for inorganic contaminants, synthetic organic contaminants, and radionuclides. POU devices are not listed for volatile organic contaminants because they do not address all routes of exposure. POE treatment units treat all of the water entering a facility (household or other building), resulting in treated water from all taps. POE devices are still considered emerging technologies because of waste disposal and cost considerations.

POE and POU treatment units often use the same technological concepts as those used in central treatment processes, but on a much smaller scale. Technologies that are amenable to the POU and POE scale treatment include activated alumina, GAC, reverse osmosis, ion exchange, and air stripping.

When POU and POE units are used by a public water system to comply with the National Primary Drinking Water Regulations (NPDWRs), the SDWA requires that the units be owned, controlled, and maintained by the public water system or by a person under contract with the public water system. This is to ensure that the units are properly operated and maintained to comply with the MCL or treatment techniques. This will also ensure that the units are equipped with the required mechanical warnings to automatically alert the customers to the occurrence of operational problems.

## ***B. Discussion of Water Treatment Techniques for Specific EDC Removal***

The EDCs addressed in this document that are included in the NPDWRs as drinking water contaminants are methoxychlor, DDT and DDE, endosulfan, PCBs, DEP, and DEHP. The EDCs in this section are grouped by chemical class. Removal techniques for the EDCs not listed in the NPDWRs will be based on removal of similar contaminants that are listed.

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The treatment processes are described with considerations of advantages, limitations, and special considerations. The actual choice of a process to include in a treatment train will ultimately depend on the source water quality, the nature of the contaminant to be removed, the required quality of the finished water, and the size of the drinking water system.

### **Methoxychlor**

The BAT for removal of methoxychlor from drinking water is GAC. Steiner and Singley (1979) have tested a wide range of water treatment processes and found GAC to be the most efficient for removal of methoxychlor. They found that over a broad range of concentrations (ranging from 1 mg/mL to 25 mg/mL) the GAC process could remove sufficient quantities of methoxychlor so that the finished water met MCL requirements which is 0.1 mg/mL.

### **Endosulfan**

The BAT for removal of endosulfan from drinking water is GAC. In the Dobbs and Cohen report "Carbon Adsorption for Toxic Organics," EPA/600/8-80/023, the following K values, as determined by the Freundlich equation and actual test were determined: alpha-endosulfan-6135, beta-endosulfan-1990, endosulfan sulfate-2548. For small system compliance, GAC, POU-GAC, and PAC can be used to remove endosulfan from drinking water supplies. Please see Table 1.

### **DDT**

The BAT for removal of DDT from drinking water is GAC. In the Dobbs and Cohen report "Carbon Adsorption for Toxic Organics," EPA/600/8-80/023, the following K values, as determined by the Freundlich equation and actual test were determined: DDT has a K value of 10,449  $\mu\text{g/g (L/\mu\text{g})}^{1/n}$  which is sufficiently above the cutoff point of 200  $\mu\text{g/g (L/\mu\text{g})}^{1/n}$  to be judged an effective treatment method and DDE (a DDT metabolite with endocrine activity) of 18,000  $\mu\text{g/g (L/\mu\text{g})}^{1/n}$ .

### **Diethyl Phthalate**

The BAT for removal of diethyl phthalate from drinking water is GAC. In the Dobbs and Cohen report "Carbon Adsorption for Toxic Organics," EPA/600/8-80/023, the following K value, as determined by the Freundlich equation and actual test for diethyl phthalate yielded a K value of 17,037  $\mu\text{g/g (L/\mu\text{g})}^{1/n}$ .

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## ***Di-(2ethylhexyl) Phthalate (DEHP)***

The BAT for removal of DEHP from drinking water is GAC. In the Dobbs and Cohen report "Carbon Adsorption for Toxic Organics," EPA/600/8-80/023, the following K value, as determined by the Freundlich equation and the test was determined. DEHP has a K value of 8,308  $\mu\text{g/g (L/\mu\text{g})}^{1/n}$  which is one of the highest values established among the 130 compounds that they tested; GAC is very effective for the removal of DEHP from drinking water.

## **PCBs**

In the Dobbs and Cohen report two studies were reported for PCB-1221 and PCB-1232. The K value determined for PCB-1221 was 1,922  $\mu\text{g/g (L/\mu\text{g})}^{1/n}$  and the K value for PCB-1232 was 4,067  $\mu\text{g/g (L/\mu\text{g})}^{1/n}$ . Both mixtures are among the lesser chlorinated groups containing 21 and 32% chlorine, respectively. Relative to other PCB mixtures they are more hydrophilic and hence would have lower K values than the commercial PCB mixtures, Aroclor 1242, 1248, 1254, and 1260. The most troublesome PCB environmental mixtures tend to be derivatives of this later group of compounds; therefore, GAC should be a very effective method for removal of environmental PCB compounds from drinking water.

## **Dioxin**

Dioxin is not water soluble, hence it is not likely to be present in untreated drinking water unless it would be attached to sediment in raw water. Because most conventional water treatment methodologies such as coagulation-sedimentation and filtration are effective in removing sediment, it is likely that these processes would be very effective in the removal of the contaminant, dioxin.

## **Alkylphenols and Alkylphenol Ethoxylates**

GAC is best used for removal of these contaminants from drinking water. Previous laboratory-scale testing for removal of nonylphenol with GAC has yielded K values of 19,406 at a water pH of 7.0. For consistency of removal of synthetic organic chemicals, GAC, POU-GAC, and PAC are recommended for small system compliance. GAC devices include pour-through for treating small volumes, faucet-mounted for POU, in-line for treating large volumes at several faucets, and high volume commercial units for treating community water supply systems. Careful selection of the type of

carbon is based on the specific contaminants in the water and the manufacturer's recommendations. Site-specific conditions may affect the percentage removal using these techniques, including the presence of "competing" contaminants. Source water-specific testing will be needed to ensure adequate removal. For GAC, surface waters may require pre-filtration. PAC is most applicable to those systems that already have a process train including mixing basins, precipitation or sedimentation, and filtration.

**Table 1.** Isotherm Constants for Selected EDCs

Chemical	Isotherm Constants (K value)	1/N	Calculated Value $\mu\text{g/gm (L}/\mu\text{g)}^{1/N*}$
Alpha-endosulfan	194	.50	6,135
Beta-endosulfan	615	.83	1,990
Endosulfan sulfate	686	.81	2,548
DDT	332	.50	10,499
DDE	232	.37	18,000
Diethyl phthalate (DEP)	110	.27	17,037
Diethylhexyl phthalate (DEHP)	11,300	1.50	8,308
PCB-1221	242	.70	1,922
PCB-1232	630	.73	4,067
Nonylphenol	250	.37	19,406

\*Any value above 200 is considered to be economically feasible.

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