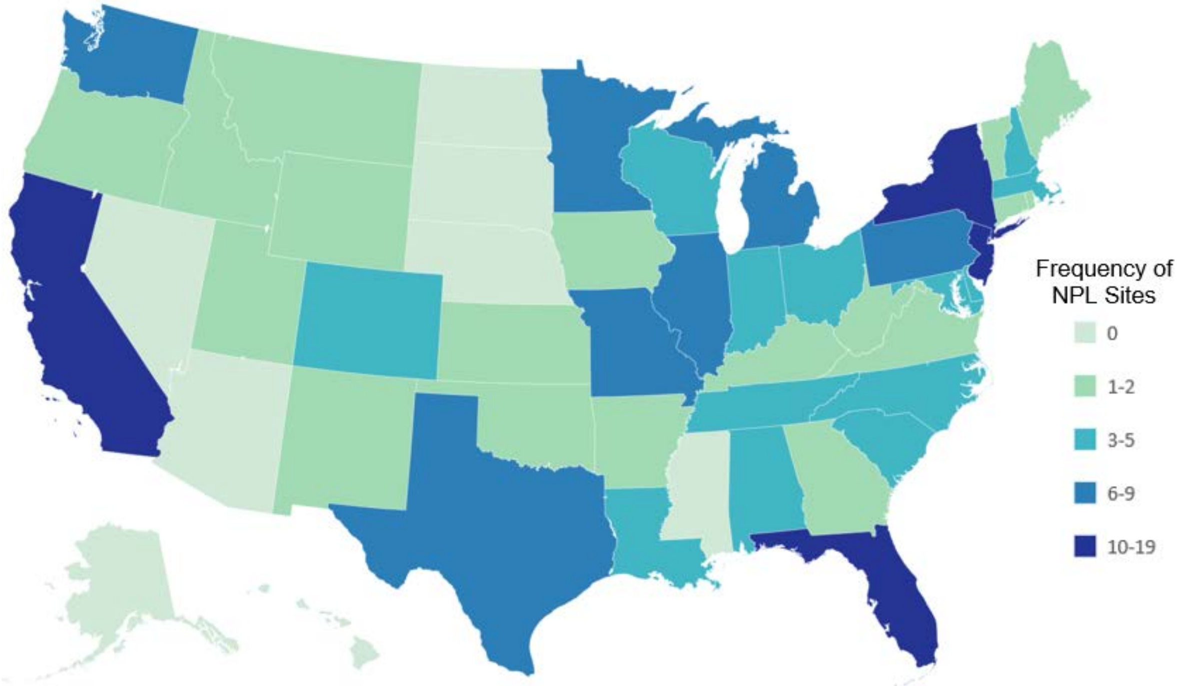
CHAPTER 5. POTENTIAL FOR HUMAN EXPOSURE

5.1 OVERVIEW

Chlorophenols have been identified in at least 191 of the 1,867 hazardous waste sites that have been proposed for inclusion on the EPA National Priorities List (NPL) (ATSDR 2019). However, the number of sites in which chlorophenols have been evaluated is not known. The number of sites in each state is shown in Figure 5-1. Of these sites, 190 are located within the United States, 1 is located in Puerto Rico (not shown).

Figure 5-1. Number of NPL Sites with Chlorophenols Contamination



Source: ATSDR 2019

- The general population can be exposed to chlorophenols from ingestion of drinking water and inhalation of ambient air.
- The chlorophenols in this profile have rarely been detected in food items, but have been shown to migrate from packaging materials used in some food containers.
- Most chlorophenols are used to produce other chemicals and exposure through their presence in consumer products is expected to be low.
- Chlorophenols have been detected in ambient air, surface water, groundwater, and soil.

- The environmental fate and transport of chlorophenols are pH-dependent since they can exist as the fully protonated phenol or its conjugate base (phenolate anion).
- Under acidic conditions, chlorophenols have greater tendency to volatilize and adsorb to soil surfaces. Under neutral to alkaline conditions, volatilization from water and moist soils decreases and mobility in soils increases.
- The chlorophenols in this profile are considered to possess low to moderate bioconcentration potential.
- Chlorophenols are considered moderately persistent, and resistance to biodegradation increases with increasing chlorine content and the location of the chlorine atoms on the aromatic ring.

The majority of known environmental releases of chlorophenols were to surface water (EPA 1982). The principal point source of water pollution by chlorophenols is industrial waste discharge; another point discharge is the leaching of chlorophenols from landfills. Chlorophenols are also formed during the disinfection process in municipal and industrial water treatment processes that use chlorination (Feng et al. 2019). Chlorophenols enter the atmosphere through volatilization, with mono- and dichlorophenols being the most volatile. The primary nonpoint source pollution of chlorophenols comes from the application of pesticides that are made from chlorophenols and the chlorination of wastewater containing phenol.

Once released to the environment, chlorophenols are subject to a series of physical, chemical, and biological transformations. Sorption, volatilization, degradation, and leaching are the primary processes governing their fate and transport. The pH in water, soil, and sediment is a major factor affecting the fate and transport of chlorophenols in these media, since the degree to which the compounds ionize increases with increasing pH. In addition, physiochemical properties of chlorophenols such as water solubility, Henry's law constant, organic carbon sorption coefficient, volatilization rate, and photolysis rate determine transport processes. Important environmental parameters influencing these processes include organic matter content and clay content in soil, sediment, and water, as chlorophenols are, in general, preferentially adsorbed to these soil constituents. In general, as the number of chlorine molecules increase, there is a reduction in vapor pressure, an increase in boiling point, and a reduction in water solubility of the chlorophenols (Solomon et al. 1994). Therefore, increasing chlorination increases the tendency of these compounds to partition into sediments and lipids and to bioconcentrate. Chlorophenols are subject to abiotic and biotic degradation and transformations. However, compounds containing chlorine in the meta positions show greater resistance to microbial attack.

The general population may be exposed to chlorophenols through ingestion of chlorinated drinking water and food contaminated with the compounds and inhalation of contaminated air. Exposure to 4-CP could also occur through its use as a root canal packing. Populations with potentially unusually high exposure to chlorophenols generally include employees of facilities that manufacture or use chlorophenols and their derivatives and those who live in the vicinity of chlorophenol-containing waste disposal sites and waste incinerators.

5.2 PRODUCTION, IMPORT/EXPORT, USE, AND DISPOSAL

5.2.1 Production

The chlorinated phenols are manufactured by chlorination of phenol, or for the higher chlorinated phenols, the chlorination of lower chlorinated phenols at high temperatures (WHO 1989). Lower chlorinated phenols (mono-, di-, and trichlorophenols) are synthesized via chlorination of phenol with chlorine gas in a melt in cast-iron reactors (Muller and Caillard 2011). The distribution of isomers can be controlled by the level of chlorination and by recycling various intermediates that are formed. The manufacture of the tetrachlorinated phenols requires a catalyst. They are produced batchwise in nickel reactors by the chlorination of lower halogenated chlorophenols using aluminum trichloride or iron trichloride (Muller and Caillard 2011). 2,4,5-TCP, 2,3,4,5-TeCP, and 2,3,5,6-TeCP have also been produced by the alkaline hydrolysis of hexachlorobenzene (WHO 1989). Chlorophenol production can result in the formation of impurities. The main impurities of the lower mono, di-, and tri-chlorophenols are other isomers of the chlorophenol or chlorophenols with more or fewer chlorine atoms than desired. The major impurity of the higher chlorophenols (tetrachlorophenols and pentachlorophenol) are polychlorophenoxyphenols (up to several percent) (Muller and Caillard 2011). Trace quantities of chlorobenzoparadioxins and chlorobenzofuran are also found. Thermal or chemical degradation of chlorophenols can also result in the formation of polychlorinated dibenzo-*p*-dioxins, polychlorinated dibenzofurans, polychlorinated phenoxyphenols, polychlorinated diphenyl ethers, polychlorinated benzenes, and polychlorinated biphenyls (Muller and Caillard 2011; WHO 1989). Muller and Caillard (2011) have noted that the highly toxic substance, 2,3,7,8-tetrachlorodibenzo-*p*-dioxin, has never been detected in products made by chlorination reaction.

Worldwide production of chlorophenols was reported as >10,000 metric tons annually in 2009, with the majority being used for the production of agricultural chemicals (Muller and Caillard 2011).

Table 5-1 summarizes information on U.S. companies that reported the manufacture or processing of chlorophenols in 2020 to the Toxic Release Inventory (TRI) (TRI20 2021). TRI data should be used with caution since only certain types of industrial facilities are required to report. This is not an exhaustive list.

Table 5-1. Facilities that Produce, Process, or Use Chlorophenols

State[a]	Number of facilities	Minimum amount on site in pounds[b]	Maximum amount on site in pounds[b]	Activities and uses[c]
AR	1	1,000	9,999	12
MI	1	100	999	1, 5, 12, 13, 14
NE	1	1,000	9,999	12
OH	1	1,000	9,999	12
TX	3	1,000	999,999	1, 5, 6, 9, 12
UT	1	1,000	9,999	9, 12
WI	1	100,000	999,999	7

[a] Post office state abbreviations used.
[b] Amounts on site reported by facilities in each state.
[c] Activities/Uses:

1. Produce
2. Import
3. Used Processing
4. Sale/Distribution
5. Byproduct
6. Reactant
7. Formulation Component
8. Article Component
9. Repackaging
10. Chemical Processing Aid
11. Manufacture Aid
12. Ancillary
13. Manufacture Impurity
14. Process Impurity

Source: TRI20 2021 (Data are from 2020)

5.2.2 Import/Export

No recent data were located regarding the import or export volumes of chlorophenols in the United States.

5.2.3 Use

Chlorophenols are used in the production of agricultural chemicals, pharmaceuticals, biocides, and dyes, with approximately 80–90% being used for agricultural purposes (Muller and Caillard 2011). The monochlorophenols have been used as antiseptics, although they have largely been replaced in this role by other chemicals (WHO 1989). Specifically, 4-CP has been used as a disinfectant for home, hospital, and farm uses (WHO 1989) and as an antiseptic in root canal treatment (Gurney and Lantenschlager 1982). 2,4-DCP has been used for mothproofing and as a miticide (WHO 1989), while the higher chlorophenols have been used as germicides, algicides, and fungicides.

The principal use of the monochlorophenols has been as intermediates for the production of higher chlorinated phenols (WHO 1989). 2,4-DCP and 2,4,5-TCP have also been used as an intermediate, especially in the production of the herbicides, 2,4-D and 2,4,5-T (Schmied-Tobies et al. 2021; WHO 1989). In the United States, 2,4-D is still in use, while 2,4,5-T was taken off the market in 1985. 2,4,6-TCP has been used as an intermediate in the production of higher chlorinated phenols, especially 2,3,4,6-TeCP and pentachlorophenol (WHO 1989).

5.2.4 Disposal

Chlorophenols are listed as toxic substances under Section 313 of the Emergency Planning and Community Right to Know Act (EPCRA) under Title III of the Super-fund Amendments and Reauthorization Act (SARA) (EPA 1995). Disposal of wastes containing chlorophenols is controlled by a number of federal regulations (see Chapter 7).

Chlorophenols are often disposed of via incineration and precautions include the assurance of complete combustion in order to prevent the formation of toxic phosgene gas and the use of an acid scrubber to remove any halo-acids produced upon combustion (Sittig 1985). However, even after incineration, various isomers have been detected in the fly ash from municipal waste incinerators (Karasek et al. 1987; Paasivirta et al. 1985).

5.3 RELEASES TO THE ENVIRONMENT

The Toxics Release Inventory (TRI) data should be used with caution because only certain types of facilities are required to report (EPA 2005). This is not an exhaustive list. Manufacturing and processing facilities are required to report information to the TRI only if they employ ≥10 full-time employees; if their facility is included in Standard Industrial Classification (SIC) Codes 10 (except 1011, 1081, and 1094), 12 (except 1241), 20–39, 4911 (limited to facilities that combust coal and/or oil for the purpose of generating electricity for distribution in commerce), 4931 (limited to facilities that combust coal and/or oil for the purpose of generating electricity for distribution in commerce), 4939 (limited to facilities that combust coal and/or oil for the purpose of generating electricity for distribution in commerce), 4953 (limited to facilities regulated under RCRA Subtitle C, 42 U.S.C. section 6921 et seq.), 5169, 5171, and 7389 (limited S.C. section 6921 et seq.), 5169, 5171, and 7389 (limited to facilities primarily engaged in solvents recovery services on a contract or fee basis); and if their facility produces, imports, or processes

≥25,000 pounds of any TRI chemical or otherwise uses >10,000 pounds of a TRI chemical in a calendar year (EPA 2005).

5.3.1 Air

Estimated releases of 547 pounds (~0.25 metric tons) of chlorophenols to the atmosphere from 10 domestic manufacturing and processing facilities in 2020, accounted for about 13% of the estimated total environmental releases from facilities required to report to the TRI (TRI20 2021). These releases are summarized in Table 5-2.

Table 5-2. Releases to the Environment from Facilities that Produce, Process, or Use Chlorophenols[a]

		Reported amounts released in pounds per year[b]							
							Total release		
State[c]	RF[d]	Air[e]	Water[f]	UI[g]	Land[h]	Other[i]	On-site[j]	Off-site[k]	On- and off-site
AR	1	0	0	0	0	0	0	0	0
MI	1	0	0	0	0	0	0	0	0
NE	1	2	0	0	38	0	2	38	40
OH	1	0	0	0	0	0	0	0	0
TX	3	410	0	3,546	1	0	3,956	1	3,957
UT	1	0	0	0	0	0	0	0	0
WI	2	135	0	0	34	0	135	34	169
Total	10	547	0	3,546	73	0	4,093	73	4,166

[a] The TRI data should be used with caution since only certain types of facilities are required to report. This is not an exhaustive list. Data are rounded to nearest whole number.

[b] Data in TRI are maximum amounts released by each facility.

[c] Post office state abbreviations are used.

[d] Number of reporting facilities.

[e] The sum of fugitive and point source releases are included in releases to air by a given facility.

[f] Surface water discharges, wastewater treatment-(metals only), and publicly owned treatment works (POTWs) (metal and metal compounds).

[g] Class I wells, Class II-V wells, and underground injection.

[h] Resource Conservation and Recovery Act (RCRA) subtitle C landfills; other onsite landfills, land treatment, surface impoundments, other land disposal, other landfills.

[i] Storage only, solidification/stabilization (metals only), other off-site management, transfers to waste broker for disposal, unknown.

[j] The sum of all releases of the chemical to air, land, water, and underground injection wells.

[k] Total amount of chemical transferred off-site, including to POTWs.

RF = reporting facilities; UI = underground injection

Source: TRI20 2021 (Data are from 2020)

Only a small fraction (approximately 5%) of chlorophenols (based on 2-CP, 2,4-DCP, and 2,4,6- TCP) are emitted to the atmosphere (EPA 1982). These releases are primarily in vapor form and are principally associated with chlorophenol production and its use in the manufacture of end-use products (EPA 1982).

Releases of chlorophenols to the atmosphere may also occur through the incineration of chlorinated wastes. 2,4-DCP has been detected in atmospheric emissions from the combustion of municipal solid waste, hazardous waste, coal, wood, and 2,4-DCP-based herbicides (Gomez et al. 1988; Junk et al. 1986; Oberg et al. 1989; Paasivirta et al. 1985). Trichlorophenols have been detected in flue gas condensates and fly ash from municipal incinerators (Viau et al. 1984). Di-, tri-, and tetrachlorophenols have also been detected in fly ash from wood, oil, and coal-fired power plants at concentrations in the ng/g level (Paasivirta et al. 1985).

5.3.2 Water

There were no estimated releases of chlorophenols to surface water from the 10 domestic manufacturing and processing facilities in 2020, from facilities required to report to the TRI (TRI20 2021).

Historically, the majority (85%) of known environmental releases of three chlorophenols (2-CP, 2,4-DCP, and 2,4,6-TCP) were to surface water (EPA 1982). The estimated 1977 water emissions of 2,4-DCP were 741,000 pounds from U.S. production facilities (EPA 1982). Industrial waste discharge is a point source of water pollution by mono- and dichlorophenols (Krijgsheld and van der Gen 1986; Mohammadi et al. 2017). Monochlorophenol concentrations of between 10 and 20 μg/L have been released in wastewater produced during the manufacture of specialty chemicals (Buikema et al. 1979; Hites et al. 1979), and 5.3 μg/L of 4-CP was detected in a bleaching effluent released to surface water from a straw mill (Folke and Lindgaard-Jorgensen 1985). 2,4-DCP or 2,4,6-TCP were also detected in effluents discharged from industries that manufacture iron and steel, electrical components, photographic equipment/supplies, pharmaceuticals, and organic chemicals/plastics and from paper pulp and paperboard mills (EPA 1979; Paasivirta et al. 1985). Oikari et al. (1985) reported that concentrations of 2,4,6-TCP and 2,3,4,6-TeCP were higher downstream from a pulp and paper mill than upstream from the facility. Free chlorophenols were still present in water 11 km downstream from the mill. However, the release of chlorophenols to water from pulp bleaching mills is being reduced as the use of elemental chlorine for bleaching is being phased out in favor of the use of chlorine dioxide (Solomon et al. 1994). Compared to chlorine, chlorine dioxide bleaching results in the production of fewer chlorophenols, and the chlorophenols that are produced contain fewer chlorine molecules.

Other sources of discharge of chlorophenols into aquatic systems include sewage treatment plants and drinking water treatment, which can result in the chlorination of phenol. In a study of 40 Canadian potable water treatment facilities, 4-CP, 2,4-DCP, and 2,4,6-TCP are the three halogenated phenols found most frequently in samples taken from chlorinated water supplies (Sithole and Williams 1986). The frequency of detection ranged from 1 to 12 out of 40 samples. Mean values were <7 ng/L and the maximum values were <130 ng/L. 2-CP has also been detected in treated drinking water in the Netherlands (1 μg/L) (Buikema et al. 1979). The maximum monochlorophenol concentrations measured in river water range from 2 to 6 μg/L (Krijgsheld and van der Gen 1986).

Chlorophenols may enter groundwater systems via leaching from landfills or underground injection disposal. 2-CP has been detected in the leachate from a municipal landfill, while 2,4-DCP was found in the leachate from an industrial landfill (Brown and Donnelly 1988). 2-CP was detected in the runoff from 1 of 15 cities, while neither 2,4-DCP nor 2,4,6-TCP were detected in the runoff from 3 cities (Cole et al. 1984). Analysis of groundwater taken from 479 waste disposal sites found that 2,4-DCP was detected at 19 sites, 2-CP at 14 sites, and 2,4,5-TCP at 2 sites, while 2,3,4,6-TeCP was not detected at any of the sites (Plumb 1991).

The detection of 2,4,6-TCP in industrially unpolluted surface water in Sweden at concentrations up to 10 ng/L suggests that this compound can be formed by natural chlorination of humic substances (Grimvall et al. 1991). A laboratory investigation (Hodin et al. 1991) reported that the addition of chloroperoxidase from the fungus, *Culduriomyces fumugo*, hydrogen peroxide, and potassium chloride to bog water (pH adjusted to 3 with 100 mM phosphate) did result in the production of 2,4,6-TCP. Chloroperoxidase could also chlorinate added phenol to form 2-CP and 4-CP. These results suggest that chloroperoxidase-mediated chlorination of natural organic matter does contribute to the levels of chlorophenols (especially 2,4,6-TCP) that are found in surface water.

5.3.3 Soil

Estimated releases of 73 pounds (~0.04 metric tons) of chlorophenols to soil from 10 domestic manufacturing and processing facilities in 2020, accounted for about 2% of the estimated total environmental releases from facilities required to report to the TRI (TRI20 2021). An additional

3,546 pounds (~1.6 metric tons), accounted for about 85% of the total environmental emissions, were released via underground injection (TRI20 2021). These releases are summarized in Table 5-2.

Releases of chlorophenols to soils may occur through several processes such as disposal of manmade wastes (e.g., landfills), atmospheric deposition, and accidental releases (e.g., spills) (EPA 1982). Smith (1985) found that the herbicide 2,4-D can be degraded to 2,4-DCP following soil application. Unspecified trichloro- and tetrachlorophenols have been identified at sites composting yard waste and municipal solid waste (Malloy et al. 1993). The investigators suggested that the source was pentachlorophenol on treated wood in chipped form that had been added as a bulking agent. The use of chlorophenols as a wood preservative (predominantly 2,3,4,6-TeCP) has also resulted in the contamination of soil around sawmills where these compounds were used (Kitunen et al. 1985, 1987; Valo et al. 1984).

5.4 ENVIRONMENTAL FATE

5.4.1 Transport and Partitioning

The environmental fate and transport of chlorophenols are highly influenced by their physical and chemical properties and environmental conditions. Chlorophenols are weak acids and will exist as a combination of the free acid and its conjugate base depending upon the pH of the environmental media. The pKa of mono- and dichlorophenols is higher than the more chlorinated tri- and tetrachlorophenols (Table 4-2) and as a consequence, mono- and dichlorophenols will exist primarily as the protonated species in water and soil at typical environmental pH, whereas tri- and tetrachlorophenols will exist primarily as the conjugate base (anion).

Air. The higher vapor pressures of the monochlorophenols suggest that among the chlorophenols, these compounds are most likely to be found in air. The vapor pressures of the chlorophenols suggest that the compounds will not partition from the vapor phase to the particulate phase (Eisenreich et al. 1981). That 2,4-DCP and other chlorophenols do not partition into the particulate phase is supported by the identification of 2,4-DCP, 2,4,5-TCP, 2,4,6-TCP, and 2,3,4,6-TeCP in rain but not on rain filters (Leuenberger et al. 1985). This study indicates that gas scavenging rather than particle scavenging is the more important process for removing chlorophenols from the air (Leuenberger et al. 1985). Estimated rain/air partition coefficients at 8°C are 2.2×10^4 for 2,4-DCP and 1.8×10^4 for 2,4,5-TCP and 2,4,6-TCP combined (Leuenberger et al. 1985).

Water. The Henry's Law constants suggests that volatilization from water surfaces may be an important environmental fate parameter for the protonated chlorophenols; however, depending upon the pH of the water, a substantial fraction of the substance may exist as the conjugate base (anion), which will not volatilize. Among the chlorophenols discussed in this profile, 2-CP has the highest vapor pressure and Henry's Law constant and is therefore most likely to evaporate from water (Krijgsheld and van der Gen 1986). In laboratory studies, evaporation half-lives of 2-CP and 4-CP from water 0.38 cm deep ranged from 1.35–1.6 and 12.8–17.4 hours, respectively (Chiou et al. 1980). Since the evaporation rate is inversely related to the depth of water, extrapolation of these data indicates that-2-CP evaporation in still water 1 m deep would require approximately 15 days; evaporation would occur more rapidly in turbulent waters. The amount of volatilization of 2-CP from fine sandy soil (0.087% organic carbon), applied in spiked municipal wastewater, was too small to be directly measured (Piwoni et al. 1986).

The amount of tri- and tetrachlorophenols evaporating from water is expected to be significantly lower than the amount of monochlorophenols evaporating, since the pKa values of tri- and tetrachlorophenols are orders of magnitude lower, indicating that a much higher percentage will exist as anions in the water column. In 2-hour laboratory studies, the volatilization rates of 2,4,6-TCP from water and three soil types were determined by Kilzer et al. (1979). These rates, expressed as the percentage of applied compound per mL of water evaporated from humus, loam, sand, and water, were 0.15, 0.73, 1.05, and 1.4%, respectively, in the first hour after the addition of 50 ppb 2,4,6-TCP. Similar rates were reported during the second hour. In wind tunnel experiments, Sugiura et al. (1984) estimated a half-life of 48 hours for loss of 2,4,6-TCP from water through volatilization. An estimated 58% of 2,4,6-TCP in a nutrient solution in which tomatoes were grown was lost to the air (from photolysis and/or volatilization) over a period of 30 days (Fragiadakis et al. 1981).

Sediment and Soil. Given the range of K_{oc} values in Table 4-1, chlorophenols tend to have low to moderate mobility in soils; however, mobility is also pH-dependent. Under neutral or alkaline conditions, a greater fraction will exist in the ionic form, which has greater solubility and more mobility in soil and a greater tendency to partition into the water column rather than sediment (Shiu et al. 1994). Under acidic conditions, more of the chlorinated phenols are expected to exist in the protonated form, which tends to adsorb to soil and sediment.

The adsorption potential of 2,4-DCP, 2,4,6-TCP, and 2,3,4,5-TeCP with an aquatic humic sorbent was examined as single and mixed solutions at different acidities (pH 3, 5.5, and 7) (Peuravouri et al. 2002).

Adsorption increased with increasing chlorine content of the chlorophenols and decreasing pH of the solution. Log K_{oc} values ranged from 2.1 for 2,4-DCP at pH 7 to 3.30 for 2,3,4,5-TeCP at pH 3 for the single solution experiments and from 1.99 for 2,4-DCP at pH 7 to 3.09 for 2,3,4,5-TeCP at pH 3 for the mixed solution experiments. A slightly larger log K_{oc} (2.89) for 2,4-DCP was measured using sediment samples of varying organic carbon content obtained from the Thermaikos Gulf, Greece (Fytianos et al. 2000).

Hyun and Lee (2004) studied the sorption behavior of 2,3,4,6-TeCP, 2,4,6-TCP, 2,4,5-TCP, and 2,4-DCP in two variable charged surface soils. The first soil, A1, was characterized as a Petroferric hapludox (41% clay, 1.38% organic carbon) and the second soil, DRC, was characterized as Typic hapludox (81% clay, 1.34% organic carbon). Both soils were acidic, with the DRC soil being the more acidic of the two. Adsorption experiments using calcium chloride solutions resulted in a soil pH of 5.8 and 4.2 for the A1 and DRC soils, respectively. In each case, significantly more adsorption was observed for each chlorophenol on the DRC soil where a greater fraction of the compound was expected to exist as the free acid rather than the anion. Log K_{oc} values for 2,4-DCP, 2,4,5-TCP, 2,4,6-TCP, and 2,3,4,6-TeCP were 1.93, 2.52, 2.06, and 2.38, respectively, on the A1 soil (pH 5.8). These values increased to 2.42, 2.85, 2.59, and 3.31 for 2,4-DCP, 2,4,5-TCP, 2,4,6-TCP, and 2,3,4,6-TeCP, respectively, on the DRC soil (pH 4.2). The authors calculated the fraction expected to exist as an anion based on their pKa values and the pH of the soils. In the less acidic A1 soil, the percentage of 2,4-DCP, 2,4,5-TCP, 2,4,6-TCP, and 2,3,4,6-TeCP present as an anion was 0.88, 6.8, 31, and 72%, respectively. In the more acidic DRC soil, the percent present as an anion was 0.002, 0.18, 1.1, and 5.9% for 2,4-DCP, 2,4,5-TCP, 2,4,6-TCP, and 2,3,4,6-TeCP, respectively.

Chlorophenol groundwater contamination will occur if sufficient quantities of the chemical are present to exceed the sorption capacity of the vadose zone saturated soils (EPA 1982). Contamination is most likely in soils with low organic carbon content or high pH. Once in groundwater, sorption of chlorophenols by the solid aquifer matrix may be estimated based on log K_{ow} and organic carbon content, provided that the organic carbon content exceeds 0.1% and the aquifer pH is not sufficiently high for significant dissociation to occur (Schellenberg et al. 1984; Schwarzenbach and Westall 1985). In a natural gradient tracer test conducted within an unconsolidated aquifer, sorption was not an important factor, compared to dispersion and degradation, in the attenuation of 4-CP concentrations (Sutton and Barker 1985). The authors attributed this finding to the low organic carbon content of the aquifer sand unit, which prevented significant hydrophobic sorption.

Other Media. The bioconcentration of chlorophenols is also likely pH-dependent as greater bioconcentration is expected under acidic conditions when a higher fraction is present in the protonated species as opposed to the anion. Under environmental pH, chlorophenols tend to have low to moderate bioconcentration potential. The bioconcentration factors (BCFs) of 2-CP, 2,4-DCP, and 2,3,4,6-TeCP were measured at two concentrations in carp over 6–8-week incubation periods in a flow-through system (CITI 2019). The BCF ranges for 2-CP were 14–24 at an initial concentration of 40 µg/L and 16–29 at a starting level of 4 µg/L over a 6-week exposure period. The BCF ranges of 2,4-DCP were 7.1–69 at 30 µg/L and 10–55 at an initial concentration of 3 µg/L over an 8-week incubation period. The ranges of BCF values for 2,3,4,6-TeCP were 25–62 at an initial concentration of 10 µg/L and 36–95 at an initial concentration of 1 µg/L over an 8-week exposure period. BCFs for 2,4-DCP in Japanese medaka (*Oryzias latipes*) were determined at five different concentrations (Kondo et al. 2005). The BCF values of 2,4-DCP ranged from 340±300 at 0.235±0.060 µg/L to 92±27 at 27.3±1.6 µg/L. Generally, BCF values increased as the aqueous concentrations of the chlorophenols decreased.

Research on biomagnification of chemical residues within the aquatic food chain indicates that the potential for residue accumulation by fish through food chains is relatively insignificant (<10%) for most compounds when compared to the tissue residues resulting from the bioconcentration process (i.e., direct uptake from water) (Barrows et al. 1980). These data suggest that only those chemicals that are relatively persistent in fish tissues appear to have any potential for significant transfer through food chains (Barrows et al. 1980). A very short tissue half-life of <1 day was measured after exposure of bluegill sunfish to 2-CP was terminated (Veith et al. 1980). Therefore, due to their relatively low BCFs (<1,000) and short biological half-lives (<7 days), monochlorophenols will probably not biomagnify within aquatic food chains (Barrows et al. 1980). Data regarding the biomagnification of the higher chlorophenols were not located.

Isensee and Jones (1971) studied the uptake of 2,4-DCP from solution and soil by oats and soybeans. The compound was taken up by the plants, with the concentrations decreasing as the plants matured. At maturity, 2,4-DCP was below detection (<0.001 µg/g) in oat seeds and 0.003 µg/g in soybeans. Data regarding the uptake of other chlorophenols by plants were not located.

The bioaccumulation of 2,3,4,6-TeCP was examined in earthworms (*Lumbricus rubellus* and *Aporrectodea caliginosa tuberculata*) at a sawmill that had been closed for 28 years before sampling (Haimi et al. 1992). At a distance of 5 m from the dipping basin, 2,3,4,6-TeCP concentrations were 430 and 1,980 µg/g fat in *Lumbricus* and *Aporrectodea*, respectively, while the soil concentration was

336 μg/g dry soil. The difference between the two genera was attributed to greater ingestion of contaminated soil by *Aporrectodea*. Additional data regarding bioaccumulation of chlorophenols in terrestrial organisms were not identified. It is not known whether 2,3,4,6-TeCP biomagnifies up the terrestrial food chain. Based on physical properties (i.e., log K_{ow}), the tetrachlorophenols, rather than lower chlorinated phenols, would have the greatest potential to biomagnify.

5.4.2 Transformation and Degradation

Air. Chlorinated phenols are expected to be degraded via reaction with photochemically generated hydroxyl radicals. Using the method of Meylan and Howard (1993), a range of atmospheric half-lives of approximately 0.54 days (2-CP) to 19.3 days (2,3,4,6-TeCP) has been estimated for the vapor-phase reaction using an average hydroxyl radical concentration of 1.5×10^6 molecule/cm^3.

Water. Both direct photolysis and the reaction of chlorophenols with hydroxyl radicals and singlet oxygen produced by ultraviolet radiation may be important processes of chlorophenol degradation near the water surface. Photolysis of monochlorophenols in water results in dechlorination, with the position of the chlorine on the ring strongly influencing the transformation (Boule et al. 1982). In the molecular form, 2-CP is converted into pyrocatechol. However, in the anionic form, it is reduced in a cyclopentadienic acid and dimerizes. For 3-CP, the photochemical product is resorcinol regardless of the pH. For 4-CP, hydroquinone is formed along with polyphenolic oligomers (Boule et al. 1982). The photolysis rates of 2-CP in natural waters depends on pH, season, and dissolved organic material (Kawaguchi 1992a, 1992b). In all cases, the reaction rate is first-order. Based on empirical data, the study authors proposed that direct photolysis of 2-CP may only occur in natural waters at pH between 7 and 9. Indirect photolysis in lake waters was only significant in summer months; in sea waters, indirect photolysis has a more significant role in the spring and fall. Kawaguchi (1992a, 1992b) also found that the dissolved organic matter in pond water does not contribute to indirect photolysis as significantly as a humic acid solution.

The photocatalytic degradation process with titanium dioxide particles has been shown to be feasible for achieving a high degree of removal of 2-CP in water (Ku et al. 1996), with almost complete disappearance in only a few hours of illumination time. However, the demineralization of reaction intermediates requires a longer time, and was found to be more effective for acidic solutions. Increasing the light intensity would significantly increase the decomposition rate of 2-CP at pH 3, but not pH 11.

The higher removals at acidic conditions may be due to the increased amounts of undissociated 2-CP species adsorbed on the TiO_2 surface, with the TiO_2 acting as a catalyst in the photochemical degradation.

The reaction of hydroxyl radicals with mono- and dichlorophenols was studied by Kochany and Bolton (1991) using spin trapping with electron paramagnetic resonance detection of spin adducts. The reaction rate of 4-CP (3.2/10^{10} M^{-1}second^{-1}) and 2,4-DCP (3.8/10^{10} M^{-1}second^{-1}) with hydroxyl radicals was greater than the reaction rate of 2-CP (1.92/10^{10} M^{-1}second^{-1}). The observation that chlorophenols with *meta*-substitution have even slower reaction rates (1.04/10^{10} M^{-1}second^{-1} for 3-CP, 0.9/10^{10} M^{-1}second^{-1} for 3,5-DCP) indicates that for the mono- and dichlorophenols, the location of chlorine rather than the number of chlorines is more important in determining the reaction rate. Higher chlorinated phenols were not examined in this study. Chlorophenols may also be removed via reaction with photochemically produced singlet oxygen in natural waters. The estimated half-life for the reaction of 2,4-DCP at pH 7 and 2,4,6-TCP with singlet oxygen at pH 5.5 under midday sun (assuming a singlet oxygen concentration of $4x10^{-14}$) using experimentally determined rate constants is 62 hours (Scully and Hoigne 1987). The rate of reaction of singlet oxygen with 2,4-DCP and 2,4,6-TCP increased significantly as the solution pH was raised from 5.5 to 9 (Scully and Hoigne 1987). This observation is consistent with a study by Tratnyek and Hoigne (1991),which found that the reaction of phenolate ions with singlet oxygen was about 1 order of magnitude greater than the reaction of the undissociated chlorophenol. The compounds examined in this study were 2-CP, 4-CP, 2,4-DCP, and 2,4,6-TCP. Although tetrachlorophenols are most likely to exist as ions in natural waters, it is not known whether the ions react more readily with singlet oxygen than the undissociated tetrachlorophenol compounds.

Hwang et al. (1986) studied the photolysis and microbial degradation of 4-CP, 2,4-DCP, and 2,4,5-TCP in both estuarine and distilled water. Photolysis was the primary transformation process for 2,4-DCP and 2,4,5-TCP, with the rate of photolysis decreased in the order 2,4,5-TCP, 2,4-DCP, and 4-CP. The rate of photolysis of 2,4-DCP was greater in estuarine water compared to distilled water, suggesting a photosensitized reaction. The type of water had no effect on the photolysis of 4-CP and 2,4,5-TCP. Unlike the polychlorinated phenols, microbial degradation was the primary transformation process for 4-CP (Hwang et al. 1986). 2-CP, 2,4-DCP, and 2,3,4,6-TeCP were all shown to be not readily biodegradable following a 4-week incubation period in an activated sludge inoculum and the Japanese MITI test (Organisation for Economic Cooperation and Development [OECD] 301C guideline) (CITI 2019).

There are numerous studies regarding the microbial degradation of chlorophenols in water and sediments (Abrahamsson and Klick 1991; Aly and Faust 1964; Banerjee et al. 1984; Genther et al. 1989; Hwang et al. 1986; Vaishnav and Korthals 1988), as well as numerous studies concerning the degradation of these compounds by sludge (Armenante et al. 1992; Battersby and Wilson 1989; Boyd and Shelton 1984; Liu and Pacepavicius 1990; Tabak et al. 1981). Although as a group, chlorophenols are poorly biodegradable and persistent in the environment, several studies have shown that aerobic degradation of chlorophenol congeners is possible (Armenante et al. 1992; Steiert et al. 1987). The aerobic degradation of chlorophenols by microorganisms requires the participation of the oxygenase enzymes to incorporate atmospheric oxygen into their substrates. For fission of the benzene nucleus, the ring is usually first dihydroxylated by an oxygenase such that two hydroxyl groups are situated either *ortho* or *para* to one another on the ring (Steiert and Crawford 1985). Subsequent ring fission occurs through another oxygenase-catalyzed reaction involving the insertion of dioxygen into the aromatic nucleus. The crucial step in the biodegradation of chlorophenols is the removal of the chlorine substituents. For the catabolism of the lesser substituted phenols (mono- and dichlorophenols), dioxygenase from chlorophenol-degrading bacteria usually opens the dehydroxylated aromatic ring before dechlorination takes place (Steiert and Crawford 1985). With more highly substituted phenols, some of the chlorosubstituents must be removed before ring cleavage since the halogen atoms deactivate the aromatic nucleus to electrophilic attack by dioxygenases.

It has been reported that 4-CP can be partially or completely degraded by several aerobic bacteria such as *Pseudomonas* sp. B13 (Knackmuss 1978) and *Azobactirium* sp. GPl (Wieser et al. 1997). The catabolic degradation routes for mono- or dichlorophenols are known to be *meta*- and modified *ortho*- pathways (Bae et al. 1996). In these pathways, 4-CP is hydroxylated to 4-chlorocatechol, which then undergoes intradiol cleavage before the chloro-substituent is removed. In addition, 4-CP degradation by *Azobactirium ureufaciens* CPR706 was reported via a pathway in which the chloro-substituent of 4-CP was replaced with an incoming hydroxyl group to form hydroquinone (Bae et al. 1996). Patel et al. (2021) demonstrated the efficacy of 4-CP degradation using batch and continuous packed bed reactors with *Bacillus subtilis* isolated from wastewater of a nearby motor vehicle service center. After 4-CP degradation was completed, the accumulated hydroquinone disappeared from the medium via ring fission forming the 4-hydroxymuconic semialdehyde intermediate. The general observation of these studies is that compounds with a chlorine in the *meta*- and/or *para*- position are the most resistant to degradation (Abrahamsson and Klick 1991). In addition, if the bacteria have not been cultured in the presence of a chlorophenol, they require an adaption period before the compounds can be degraded. For example, degradation of 2,4-DCP was observed in natural water collected from a river following lag times of

2.5 and 8.3 days for two separate collections (Banerjee et al. 1984). The rates of degradation of 4-CP, 2,4-DCP, and 2,3,4,5-TeCP in river water were 6.5×10^{-6}, 2.3×10^{-6}, and 1.4×10^{-7} moles/hour, respectively (Banerjee et al. 1984). A study by Liu and Pacepavicius (1990) indicates that the position, rather than the number of chlorine atoms, is more important in determining the biodegradation of chlorophenols. The biodegradation of chlorophenols was studied in both aerobic and anaerobic systems using a pentachlorophenol-degrading bacterial culture. The results, shown in Table 5-3, indicate lag time to degradation, and half-life tended to be shorter for compounds with a chlorine in the 4 position and longer for compounds with a chlorine at the 5 position. Anaerobic degradation of the chlorophenols required a longer lag time and the half-lives were longer.

Table 5-3. Degradation of Chlorophenols by Bacteria Adapted to Pentachlorophenol Under Different Oxygen Conditions

	Lag period hours		Degradation half-life (hours)	
Substance	Aerobic conditions	Anaerobic conditions	Aerobic conditions	Anaerobic conditions
2-Chlorophenol	25	250	140	75
4-Chlorophenol	25	51	88	84
2,4-Dichlorophenol	0	310	125	430
2,4,5-Trichlorophenol	300	Undegraded	380	Undegraded
2,4,6-Trichlorophenol	0	300	120	470
2,3,4,5-Tetrachlorophenol	50	500	165	510
2,3,5,6-Tetrachlorophenol	Undegraded	Undegraded	Undegraded	Undegraded

Liu and Pacepavicius (1990)

Reductive dehalogenation of chlorinated aromatic compounds whereby chlorines are being replaced by hydrogens occurs extensively under anaerobic conditions (Steiert and Crawford 1985). Anaerobic dehalogenation of 2-CP, a common intermediate of polychlorophenol degradation, by mixed cultures was reported (Themel et al. 1996). Acetate was found to be the major end product, with phenol and benzoate as intermediate products, but CO_2 was not found to be an end product.

A study of anaerobic degradation of chlorophenols in wastewater in an upflow anaerobic sludge blanket reactor indicated that the higher chlorophenols were converted to lower chlorinated compounds via reductive dechlorination reactions (Woods et al. 1989). The rate of these reactions was dependent on the position of the chlorine; chlorines adjacent to the hydroxyl group were preferentially removed, and *meta* chlorines were removed following acclimation, with no evidence for the removal of *para* chlorines. Woods et al. (1989) also found no evidence for the dechlorination of monochlorophenols in this system.

4-CP was demonstrated to be quickly removed from formulated wastewater catalyzed by horseradish peroxidase (Zhang et al. 1997) to form radicals or quinones, which might be subsequently polymerized to form less-soluble large molecules and precipitated from aqueous phase. The flocculant might increase the removal percentage of the pollutant through enhancing the sedimentation of the reaction products. The optimum pH for the removal efficiency of chlorophenol was 9.0. The analytical method would, thus, have to quantify both salt and acid forms of the chlorophenol.

Sediment and Soil. Chlorophenol isomers undergo biodegradation in soils under aerobic conditions. Aerobic microorganisms that can degrade chlorophenols have been isolated from soil bacterial cultures. *Pseudomonas picketti* DTP0602, which used 2,4,6-TCP as the sole source of carbon and energy, was isolated from mixed cultures of soil bacterial populations that had been acclimatized to 2,4,6-TCP (Kiyohara et al. 1992). This bacterial species dechlorinates the phenol at position 4 of various chlorophenols to yield their corresponding hydroquinones and may involve oxygenation. Two different enzyme systems for hydroxylation at the *ortho* and *para* positions of the phenol ring may be present in this bacterial species. The *para*-hydroxylation system, which may use a monooxygenase, possibly involves the dechlorination of a 4-position chlorine atom of chlorophenols. 2,4,6-Trichlorophenol-4-monooxygenase, a dehalogenating enzyme, was also isolated from trichlorophenol-degrading soil bacterium *Azotobacter* sp., strain GPl (Wieser et al. 1997). NADH, flavin adenine dinucleotide, and O_2 are required as cofactors. 2,6-Dichlorohydroquinone and Cl^- ions were identified as reaction products. Trichlorophenol was the best substrate for this enzyme. However, the majority of other chlorophenols converted by the enzyme bear a chloro-substituent in the 4-position. 2,6-DCP, also accepted as a substrate, was hydroxylated in the 4-position to 2,6-dichlorohydroquinone in a nondehalogenating reaction. It was also reported that the addition to the culture medium of a vitamin solution containing biotin, folic acid, pyridoxine hydrochloride, riboflavin, thiamine hydrochloride, niacin, pantothenic acid, cyanocobalamin, *p*-aminobenzoic acid, and thioctic acid can increase the aerobic degradation and dechlorination of 2-CP and 4-CP by *Pseudomonas picketti* strain LDl culture by 11–16% (Kafkewitz et al. 1996).

The extent and rate of biodegradation depend on numerous factors, including soil pH, organic carbon content, biomass, and the chlorophenol isomer and its concentration. In neutral clay-loam soil at 20°C under aerobic conditions, 2-CP was degraded the fastest (Baker and Mayfield 1980). Decomposition rates were as follows: 100% of the 2-CP in 1.5 days, 95% of the 2,4,6-TCP in 3 days, 83% of the 4-CP in 20 days, 81% of the 2,4-DCP in 40 days, and 72 and 31% of the 2,4,5-TCP and 2,3,4,5-TeCP, respectively, in 160 days (Baker and Mayfield 1980). Dasappa and Loehr (1991) examined the loss of 2-CP, 4-CP, 2,4-DCP, and 2,4,6-TCP from a laboratory soil microcosm. The loss from soil and the water-soluble fraction were examined at two concentrations for each compound. The loss of chlorophenols from the water-soluble fraction was about 1.5 times greater than the loss from soil, and chemical loss was slower at higher initial concentrations. Mineralization of 2,4,5-TCP in soil not previously exposed to chloroorganics has been reported (Matus et al. 1996). The observation of 2,3,4,6-TeCP in soil (157–338 μg/g dry soil) at a sawmill 28 years after it closed provides evidence that this compound can persist in soil. Soil concentrations of 2,3,4,6-TeCP when the mill was closed were not stated. In general, degradation or complete mineralization to carbon dioxide (CO_2) is greater in soils with low organic carbon content (Kjeldsen et al. 1990), slightly alkaline pH (Balfanz and Rehm 1991), increased temperatures (Baker and Mayfield 1980; Baker et al. 1980; Balfanz and Rehm 1991), and increased inoculum concentrations (Balfanz and Rehm 1991).

Microbial degradation of chlorophenols in soil under anaerobic conditions has not been observed consistently. For 2-CP, 4-CP, 2,4-DCP, 2,4,5-TCP, 2,4,6-TCP, and 2,3,4,5-TeCP, no statistically significant differences in degradation rates between nonsterile and sterile clay loam soils occurred when both soil samples were incubated under anaerobic conditions (Baker and Mayfield 1980).

In a study of the degradation of halogenated phenols in anoxic marine sediments, the main degradation pathway was progressive dehalogenation with ortho > para > meta. Sediments that had been exposed to effluent water from a paper and pulp mill showed a higher dehalogenation potential (Abrahamsson and Klick 1991).

Another study demonstrated that anaerobic degradation of chlorophenols with an estuarine sediment inoculum was coupled to sulfate reduction, which was the electron sink. The relative rates of degradation were 4-CP > 3-CP > 2-CP, 2,4-DCP (Haggblom and Young 1990).

5.5 LEVELS IN THE ENVIRONMENT

Reliable evaluation of the potential for human exposure to chlorophenols depends, in part, on the reliability of supporting analytical data from environmental samples and biological specimens. Concentrations of chlorophenols in unpolluted atmospheres and in pristine surface waters are often so low as to be near the limits of current analytical methods. In reviewing data on chlorophenols levels monitored or estimated in the environment, it should also be noted that the amount of chemical identified analytically is not necessarily equivalent to the amount that is bioavailable.

Table 5-4 shows the lowest limits of detections that are achieved by analytical analysis in environmental media. de Morias et al. (2012) reviewed extraction and chromatographic techniques for the detection of chlorophenols in environmental media (water, sludge, soil, and sediment), biological samples, and food. An overview summary of the range of concentrations detected in environmental media is presented in Table 5-5.

Table 5-4. Lowest Limit of Detection Based on Standards[a]

Media	Detection limit	Reference
Air[b] (ppbv)	$2x10^{-5}$ $9.4x10^{-7}$–$1.2x10^{-5}$ (for 250 m^3 sample volume)	Leuenberger et al. 1985 Schummer et al. 2006
Drinking water (ppb)	0.02	EPA 2000
Surface water and groundwater (ppb)	$1x10^{-4}$	Grimvall et al. 1991
Soil (ppb)	0.007	de Morais et al. 2012
Sediment (ppb)	1	de Morais et al. 2012
Urine (ppb)	0.1	CDC 2019, 2021

[a]Detection limits based on using appropriate preparation and analytics. These limits may not be possible in all situations and may be different for different chlorophenols.
[b]Detection limits in air are dependent upon sampling times and sampling volumes.

Table 5-5. Summary of Environmental Levels of Chlorophenols

Media	Low	High	For more information
Outdoor air (ppbv)	<LOD	190	Section 5.5.1
Surface water (ppb)	<LOD	17	Section 5.5.2
Ground water (ppb)	<LOD	80	Section 5.5.2
Drinking water (ppb)	<LOD	0.15	Section 5.5.2
Soil (ppb)	<LOD	338,000	Section 5.5.3

Detections of chlorophenols in air, water, and soil at NPL sites are summarized in Table 5-6.

Table 5-6. Chlorophenols Levels in Water, Soil, and Air of National Priorities List (NPL) Sites

Medium	Median[a]	Geometric mean[a]	Geometric standard deviation[a]	Number of quantitative measurements	NPL sites
2-Chlorophenol					
Water (ppb)	73	73.0	11.7	9	8
Soil (ppb)	38,200	32,200	32.3	15	9
Air (ppbv)	No data	No data	No data	No data	No data
4-Chlorophenol					
Water (ppb)	39	66.9	3.04	3	2
Soil (ppb)	No data	No data	No data	No data	No data
Air (ppbv)	No data	No data	No data	No data	No data
2,4-Dichlorophenol					
Water (ppb)	1,250	622	26.8	10	7
Soil (ppb)	160,000	36,800	45.0	21	14
Air (ppbv)	No data	No data	No data	No data	No data
2,4,5-Trichlorophenol					
Water (ppb)	5,210	3,280	2.23	3	2
Soil (ppb)	253	341	6.56	5	5
Air (ppbv)	No data	No data	No data	No data	No data
2,4,6-Trichlorophenol					
Water (ppb)	240	245	22.0	11	9
Soil (ppb)	108,000	26,100	33.8	16	12
Air (ppbv)	No data	No data	No data	No data	No data
Tetrachlorophenol					
Water (ppb)	23.5	13.9	62.0	6	4
Soil (ppb)	263,000	87,500	12.1	2	2
Air (ppbv)	No data	No data	No data	No data	No data

[a] Concentrations found in ATSDR site documents from 1981 to 2019 for 1,867 NPL sites (ATSDR 2019). Maximum concentrations were abstracted for types of environmental media for which exposure is likely. Pathways do not necessarily involve exposure or levels of concern.

5.5.1 Air

Air samples collected in a rural area in France had detectable levels of multiple chlorophenols (Schummer et al. 2006). Maximum values ranged from 130.6 (3,4-DCP) to 433.3 pg/m^3 (2,3,4-TCP). These data are provided in Table 5-7.

Table 5-7. Levels of Chlorophenols in Atmosphere of Samples Collected in Winter 2004 in Strasbourg, France

Chlorophenol	Frequency of quantification	Mean (range) pg/m^3
2-CP	15	68.9 (LQ–172.5)
3-CP	11	88.9 (LQ–154)
4-CP	7	74.6 (LQ–229.6)
2,6-DCP	13	123.7 (112.9–134.3)
2,5; 3,5-DCP	18	143.1 (140.2–153.2)
2,4-DCP	7	156.7 (148.6–167.2)
2,3-DCP	3	272.6 (262.6–289)
2,6-DCP	3	121.3 (LQ–30.6)
2,4,6-TCP	ND	NA (NA)
2,3,5-TCP	1	247.4 (NA–247.4)
2,3,6;2,4,5-TCP	ND	NA (NA)
3,4,5-TCP	3	277.5 (209.3–336.5)
2,3,4-TCP	9	379.8 (316.4–433.3)
2,3,5,6-TeCP	ND	NA (NA)
2,3,4,6-TeCP	2	279.8 (205–362.7)
2,3,4,5-TeCP	1	93 (ND–260.3)

CP = chlorophenol; DCP = dichlorophenol; LD = limit of detection; LQ = lower than the limit of quantitation; NA = not applicable; ND = not determined; TCP = trichlorophenol; TeCP = tetrachlorophenol

Source: Schummer et al. 2006

During seven rain events in Portland, Oregon, in 1984, 2,4-DCP was detected in the air in all seven events at an average concentration of 1.5 ng/m^3 (0.23 pptv), combined 2,4,5-TCP and 2,4,6-TCP were detected in 6/7 events at an average concentration of 0.15 ng/m^3 (0.02 pptv), and 2,3,4,6-TeCP was detected in 5/7 events at an average concentration of 0.27 ng/m^3 (0.03 pptv) (Leuenberger et al. 1985). Average concentrations in rain for the seven events were 5.9, 1.1, 1.4, and 20 ng/m^3 (0.89, 0.14, 0.17, and 2.1 pptv) for 2,4-DCP, 2,4,5-TCP, 2,4,6-TCP, and 2,3,4,6-TeCP, which were detected in 7/7, 4/7, 5/7, and 7/7 of the events, respectively. Additional data regarding ambient levels of chlorophenols in indoor or outdoor air were not identified. However, data on 2-CP levels after the accidental derailment and rupture of a train tanker are available. On the day of the accident, air concentrations ranging from 0.02 to 0.7 mg/m^3 (0.04–0.19 ppmv) were detected in the immediate vicinity of the spill (EPA 1982). Eighteen days after the spill, air levels were <2 µg/m^3 (<0.5 ppbv). No additional data are available regarding air emissions following accidental releases.

5.5.2 Water

During a 7-day sampling period, chlorophenols were detected in the Yangtze River, China using two different sampling methods (Zhu et al. 2021). Levels of 4-CP, 2,4-DCP, and 2,4,6-TCP measured with a daily grab sampling method were 37.60±0.93–47.81±1.42, 51.00±1.03–64.13±4.80, and 32.06±0.10–42.06±1.80 ng/L, respectively. Levels of the chlorophenols measured with a sampling technique using films derived from porous β-cyclodextrin polymers as binding materials (CDP-DGT) at the end of the 7-day period were reported as 45.71±3.01, 60.44±3.85, and 39.89±.03 ng/L for 4-CP, 2,4- DCP, and 2,4,6-TCP, respectively (Zhu et al. 2021). Grimvall et al. (1991) measured 2,4,6-TCP in unpolluted surface waters in remote areas of southern Sweden and in pulp bleaching plant receiving waters, Lake Vattern and the Baltic Sea. Concentrations up to 10 ng 2,4,6-TCP/L were found in unpolluted waters, with concentrations of 2,4,6-TCP in Lake Vattern decreasing from 12 to 1 ng/L with increasing distance from the bleaching plant. 2,4,6-TCP concentrations in the Baltic Sea were <1 ng/L. This study suggests that 2,4,6-TCP can be formed by both industrial and natural chlorination of humic substances, an observation that was confirmed in the laboratory (Haimi et al. 1992).

Analysis of chlorophenol concentrations downstream of paper mills along the Rainy River in Canada and northern Minnesota did not identify 2-CP, 4-CP, 2,4,5-TCP, 2,3,5,6-TeCP, or 2,3,4,5-TeCP using methods with detection limits as low as 50 ng/L (Merriman 1988). In water samples from northern Alberta, Canada, 2-CP was not detected (detection limit 0.005 µg/L), while 2,4-DCP concentrations were <0.002–7.1 µg/L, and 2,4,6-TCP concentrations were <0.002–17 µg/L (Morales et al. 1992). 2,4-DCP, 2,4,6-TCP, and 2,3,4,6-TeCP were identified in water samples from at least one of the three sampling stations. A summary of STORET data of priority pollutants in ambient water (Staples 1985) indicated that 2-CP was detected in 0.2% of 814 samples, 2,4-DCP was detected in 0.4% of 876 samples, and unspecified trichlorophenols were detected in 0.1% of 880 samples. Analysis of runoff from 15 U.S. cities for 2-CP, 2,4-DCP, and 2,4,6-TCP identified only 2-CP, which was found in samples from only one city (Cole et al. 1984).

Chlorophenols are produced during the chlorination of organic material present in industrial and municipal waste waters. Several investigators have detected these chemicals downstream of wastewater discharge points. Maximum surface water concentrations measured in 13 samples downstream from a chlorinated waste water discharge in the Netherlands were (in µg/L) 0.6 for 2-CP, 2.1 for 4-CP, 0.33 for 2,4-DCP, 0.32 for 2,4,5-TCP, 0.74 for 2,4,6-TCP, 0.02 for 2,3,4,5-TeCP, 0.2 for 2,3,4,6-TeCP, and 0.08 for 2,3,5,6-TeCP (Wegman and van de Broek 1983). Maximum monochlorophenol concentrations of between 2 and 6 µg/L have been measured in European rivers (Krijgsheld and van der Gen 1986). Zhu et al. (2021) detected 2,4,6-TCP when studying disinfection byproducts in a drinking water treatment plant in the Yangtze River Delta, China. The levels of 2,4,6-TCP in raw water and finished water were reported as 0.55 and 0.75 ng/L, respectively.

Chlorophenols have been detected in groundwater from waste disposal sites, indicating that these compounds can leach through soil (Plumb 1991). 2,4-DCP was detected most frequently, followed by 2,4,6-TCP, 2-CP, and 2,4,5-TCP. 2,3,4,6-TeCP was not detected at any of the 479 sites. It was not reported how much of each chlorophenol was disposed at each site, and soil concentrations at the sites were not reported. 2,4-DCP in the concentration range of 3.2–79.7 µg/L, as well as other organic compounds, has been found in groundwater samples taken near an abandoned creosote waste site in Conroe, Texas (Bedient et al. 1984). A study analyzing groundwater quality in the state of Ohio from 1992 to 2001 had no detections of 2,4-DCP, 2-CP, or 2,4,6-TCP in 386 samples analyzed (OhioEPA 2008).

Chlorination of drinking water at treatment plants can result in detectable levels of chlorophenols if the required precursors are available in the raw water (Krijgsheld and van der Gen 1986). In a study of Canadian potable water treatment facilities conducted in the summer, maximum concentrations of 65, 127, 72, and 148 ng/L of 2-CP, 4-CP, 2,4-DCP, and 2,4,6-TCP, respectively, were measured, while 2,3,4,5-TeCP was not detected in the water (Sithole and Williams 1986). 2,4-DCP and 2,4,6-TCP were monitored for in 304 public water systems (PWS) between 2001 and 2005 as part of the EPA Unregulated Contaminant Monitoring Rule (UCMR). The UCMR was developed to collect data for contaminants that could be present in drinking water but do not have health-based standards set under the Safe Drinking Water Act (SDWA). Neither 2,4-DCP nor 2,4,6-TCP were detected in 2,308 samples that were tested in the 304 PWS (EPA 2005).

5.5.3 Sediment and Soil

Concentrations of 2,4,5-TCP near an automobile workshop in Nigeria ranged from 0.22±0.10 to 1.02±0.47 mg/kg during the dry seasonal climate, while the mean level at a control site not located near the facility was 0.02 mg/kg (Ibeto et al. 2019). Levels during the rainy season ranged from 1.90±0.04 to 1.99±0.01 mg/kg and 2,4,5-TCP was not detected at the control site. Levels of 2,4-DCP, 2,4,5-TCP, and 2,4,6-TCP were measured in two different soil types located in Nanjing, China (Zhu et al. 2021). The concentrations of 2,4-DCP, 2,4,5-TCP, and 2,4,6-TCP were reported as 0.38±0.01, 1.06±0.04, and

0.48±0.02 mg/kg, respectively in a Kunming red loam soil. Levels of 2,4-DCP, 2,4,5-TCP, and 2,4,6-TCP were 1.81±0.02, 2.11±0.03, and 1.95±0.02 mg/kg, respectively, in a Yixing paddy soil that had a significantly greater organic matter content as compared to the loam soil. Kitunen et al. (1985) reported soil concentrations (in mg/kg wet weight) of 2.7–47.4, 2,4-DCP; 0.8–15.7, 2,4,5-TCP; 7.3–1,258.3, 2,4,6-TCP; 231–1,776.4, 2,3,4,6-TeCP; and 0.9–2.2, 2,3,4,5-TeCP in soil at an operating sawmill in Finland where chlorophenols (predominantly 2,3,4,6-TeCP) were being used as a wood preservative. The highest concentrations of chlorophenols were found at depths of 5–40 cm. Soil concentrations of 157–338 mg 2,3,4,6-TeCP/kg dry soil were found at a sawmill in Finland 28 years after it had closed, indicating that this compound can persist for long periods (Haimi et al. 1992). Soil concentrations of 2,3,4,6-TeCP when the sawmill was in operation were not reported, and soil concentrations of other chlorophenols discussed in this profile were not measured.

A limited amount of data concerning chlorophenol sediment concentrations in areas of known surface water contamination are available. 2-CP and 4-CP were not detected in sediments, while the maximum concentrations of 2,4-DCP, 2,4,5-TCP, 2,4,6-TCP, 2,3,4,5-TeCP, 2,3,4,6-TeCP, and 2,3,5,6-TeCP were 10, 15, 3.7, 9.8, 4.9, and 2.8 pg/kg, respectively (Wegman and van de Broek 1983). In the same study, none of the isomers appeared in sediment samples collected from six locations in the vicinity of chemical and industrial wastewater effluent discharge points. These findings may be misleading because of the poor sensitivity (detection limit of 10 µg/kg) of the gas chromatography/electron capture detector (GC/ECD) analytical procedure. No 2-CP, 2,4-DCP, or 2,4,6-TCP were detected in sediment samples from northern Alberta, Canada, where water concentrations of these chlorophenols were low or not detectable (Morales et al. 1992). The limits of detection in sediments were 0.02 µg/g for 2-CP and 0.01 µg/g for 2,4-DCP and 2,4,6-TCP. In a study by the United States Geological Survey (USGS) on water quality in the western lake Michigan drainages, 2-CP was analyzed for, but not detected, in fish and bed sediments sampled from 1992 to 1995 (USGS 1998a). In a similar study conducted in the lower Susquehanna River Basin of Pennsylvania and Maryland, 2-CP was also not detected in bed sediment or fish tissue (USGS 1998b).

5.5.4 Other Media

The use of the chlorophenoxy herbicides may result in contamination with 2,4-DCP and 2,4,5-TCP. For example, Cook et al. (1983) analyzed the free and acid hydrolyzable residues of 2,4-DCP in millet resulting from treatment with 2,4-D. The total residues of 2,4-DCP ranged from not detected (<0.02 ppm detection limit) to 0.031 ppm for postemergence and preharvest treatment. Only 15–19% of the 2,4-DCP residues were in the free unaltered form, while the remaining residues were conjugated to sugars and amino acids and converted to the free form by acid hydrolysis.

Chlorophenols have been detected in children's wooden toy products in China (Wang et al. 2021). A total of 90 wooden toys were collected and analyzed for chlorophenols and the insecticide, lindane. 2,4-DCP and 2,4,6-TCP had higher detection rates and contents (approximately 1–9 μg/kg) than the other compounds analyzed. The authors then studied the migration rates of these substances from the toys and estimated the exposure levels that children would be expected to have. Using 11 positive samples, the greatest migration percentages of 2,4-DCP and 2,4,6-TCP ranged from 7.1 to 20.3% and from 11.1 to 24.8%, respectively. Using these results, the authors calculated that for children aged 3–36 months, the daily average 2,4-DCP exposure level associated with wooden toys ranged from 2.7 to 46.9 pg/kg day, while the daily average of 2,4,6-TCP exposure ranged from 3.6 to 69.4 pg/kg day.

Few data were found on the levels of chlorophenols in U.S. foods. Most of the data or estimates are for concentrations in fish or shellfish; 2-CP, 2,4-DCP, and 2,4,6-TCP were not detected in 22 composite samples of fish collected from harbors and tributaries of the Great Lakes (DeVault 1985). 4-CP, 2,4-DCP, and 2,4,6-TCP were not detected (detection limit 0.02 mg/kg) in fish from 13 Lake Michigan tributaries (Camanzo et al. 1987) or in fish from northern Alberta, Canada, (detection limit 0.01 μg/g) (Morales et al. 1992). Fish in the Fraser River estuary downstream from a lumber mill were found to contain chlorophenols including 2,4,5-TCP, 2,4,6-TCP, 2,3,5,6-TeCP, 2,3,4,6-TeCP, and 2,3,4,5-TeCP (Carey et al. 1988). Among the chlorophenols discussed in this profile, 2,3,4,6-TeCP was the most predominant compound, and the highest concentrations (49 ng/g) were found in sculpin, which had concentrations of about 400 times the concentration found in water in the estuary. Trichlorophenol (combined 2,4,5- and 2,4,6- isomers) concentrations of 29–629 ppb (wet weight) were measured in fish livers collected from the Pacific Ocean 6 km northwest of the discharge zone for the Los Angeles County wastewater treatment plant by Gossett et al. (1983). Concentrations in edible tissues were not measured. de Morais et al. (2012) reported that levels of chlorophenols the Slovak Republic total diet were on the order of ng/g and they have been identified in wine, milk, clams, and honey.

A potential source for chlorophenol contamination of food is migration from packaging materials. Shang-Zhi and Stanley (1983) reported levels of 0.1–0.68 ppm 2,4,6-TCP and 0.14–0.55 ppm 2,3,4,6-TeCP in cardboard food containers. Analysis for other chlorophenols was not completed. Shang-Zhi and Stanley (1983) indicated that the source of chlorophenol contamination was polyvinyl acetate and starch adhesives used in carton manufacture.

5.6 GENERAL POPULATION EXPOSURE

Oral exposure to chlorophenol-contaminated water or inhalation of contaminated air are the main routes of exposure to the general population. Water contaminated through chlorination is most likely to contain lower chlorinated phenols, while higher chlorinated phenols are more likely to be found in fish. Although food monitoring data are lacking, exposure to chlorophenols through the ingestion of food is expected to be relatively minor. Estimates of total chlorophenol intake reviewed by WHO (1989) ranged from 2.2 µg/person/day, assuming that contaminated water and fish were the main sources of exposure, to about 10–40 µg/person/day, assuming that indoor rooms were treated with a chlorophenol preservative.

The identification of chlorophenols in urine and fat of persons not occupationally exposed to chlorophenols confirms general population exposure to these compounds. The median urinary concentration of 2,4-DCP in 726 participants of a study designed to detect endocrine-disrupting chemicals in the U.S. general population was 0.235 ng/mL (range 0.108–9.75 ng/mL) and the median concentration of 2.5-DCP was 0.81 ng/mL (range 0.210–242 ng/mL) (Dodson et al. 2020). The authors found that participants in the study who avoided using antibacterial products containing triclosan had lower levels of 2,4-DCP, which is a degradation product of triclosan, compared to those who did not use products containing triclosan. Although triclosan is no longer used in antibacterial soaps, it may still be used in other personal care products like toothpaste and deodorant and in building materials like countertops, flooring, and bathroom fixtures (Dodson et al. 2021). A followup study examined whether there were potential correlations of the urinary levels of the chemicals analyzed for individuals living in the same home since they may share exposures from direct contact with sources or indirectly through contamination of the home environment (Dodson et al. 2021). It was determined that urinary concentration of 2,5-DCP was the most strongly correlated between 185 home pair-members out of any of the 10 chemicals analyzed. The authors theorized that because 2,5-DCP is a metabolite of 1,4-dichlorobenzene, a disinfectant and pesticide used in mothballs and deodorizers, products containing this compound were likely used within the dwelling rather than personally used products and would likely affect all residents. Analysis of urine from 197 children living near a herbicide manufacturing plant in Arkansas for 2,4-DCP, 2,4,5-TCP, and 2,4,6-TCP, identified these compounds in 27, 54, and 11% of the samples, respectively (Hill et al. 1989). The 95th percentile concentrations (in ppb) were 7 for 2,4-DCP, 7 for 2,4,5-TCP, and 4 for 2,4,6-TCP. In the NHANES II, 2,4,5-TCP was detected (detection limit 5 ppb) in 3.4% of about 6,000 urine samples taken from a representative sample of nonoccupationally exposed persons from 64 communities in the United States during 1976–1980 (Kutz et al. 1992; Murphy et al.

1983). The maximum concentration detected was 56 ppb (Kutz et al. 1992). The investigators discussed that because of the considerable variability among the recovery rates over time and between laboratories, the level for 2,4,5-TCP may be underestimated. The average fat concentrations of combined 2,3,4,6-TeCP and 2,3,5,6-TeCP and of 2,3,4,5-TeCP in autopsy specimens were 22 and 6 ng/g respectively in Kingston, Ontario, which is on Lake Ontario, relative to 7 ng/g for 2,3,4,6-TeCP, 2,3,5,6-TeCP, and 2,3,4,5-TeCP in tissue from persons living in Ottawa (Williams et al. 1984). 2,3,4,6-TeCP was detected in 29/46 adipose samples from persons in Finland not occupationally exposed to chlorophenols, while 2,4,6-TCP was detected in only one adipose sample (Mussalo-Rauhamaa et al. 1989). The concentration of 2,3,4,6-TeCP in adipose tissue ranged from <0.001 (the detection limit) to 0.031 μg/g. 2,3,4,6,-TeCP was also found in 2/13 liver samples, while 2,4,6-TCP was not detected (0.001 μg/g detection limit) in any liver samples.

The most recent data for urinary levels from the fourth NHANES report are presented in Tables 5-8 and 5-9 (2,4-DCP), Tables 5-10 and 5-11 (2,5-DCP), Tables 5-12 and 5-13 (2,4,5-TCP), and Tables 5-14 and 5-15 (2,4,6-TCP) (CDC 2009, 2019, 2021).

Occupational exposure to chlorophenol isomers may occur during chemical production and during subsequent use as intermediates in the synthesis of higher chlorinated phenols, phenolic resins, dyes, and drugs (Exon et al. 1984; Krijgsheld and van der Gen 1986). Exposures result from inhalation and/or dermal contact and are most likely associated with process, storage, or fugitive emissions at chemical manufacturing plants. No estimates of the number of workers exposed to the chlorophenols discussed in this profile were available.

Occupational exposure to chlorophenols may also occur during the incineration of wastes containing chlorinated chemicals (Angerer et al. 1992, 1993) and through indirect exposure following worker inhalation and subsequent metabolism of chlorobenzene (Kusters and Lauwerys 1990; Yoshida et al. 1986). In a study of 53 municipal waste incinerator workers' urine, concentrations of 2,4-DCP and 2,4,5-TCP were small but significantly ($p=0.05$; nonparametric U-test of Wilcoxon, Mann, and Whitney) greater than the urinary concentrations of these chlorophenols in 248 persons with no known occupational exposure to organic chemicals (Angerer et al. 1992, 1993). However, 4-CP and combined 2,3,4,6-TeCP and 2,3,5,6-TeCP urine concentrations were small but significantly higher in the control group, which included 88 people from urban communities, than in the incinerator workers. The investigators suggested that the higher 4-CP urine concentrations in the urban population were a result of atmospheric exposure to

Table 5-8. Geometric Mean and Selected Percentiles of Urinary 2,4-Dichlorophenol Concentrations (in µg/L) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES) 2003–2016

	Survey years[a]	Geometric mean (95% CI)	Selected percentiles (95% CI)				Sample size
			50th	75th	90th	95th	
Total population	2003–2004	1.04 (0.895–1.21)	0.900 (0.800–1.10)	2.70 (2.30–3.10)	8.80 (6.60–11.9)	21.3 (14.1–29.5)	2,525
	2005–2006	0.945 (0.791–1.13)	0.800 (0.700–1.00)	2.00 (1.60–2.40)	4.90 (3.90–6.30)	11.9 (7.00–20.4)	2,548
	2007–2008	0.970 (0.852–1.11)	0.800 (0.700–.900)	1.80 (1.50–2.30)	5.10 (3.80–7.60)	12.6 (9.00–18.1)	2,604
	2009–2010	0.803 (0.729–.885)	0.700 (0.700–.800)	1.50 (1.40–1.70)	4.00 (3.30–5.00)	8.80 (6.40–15.7)	2,749
	2011–2012	0.695 (0.619–0.781)	0.600 (0.600–0.700)	1.30 (1.10–1.60)	3.50 (2.80–4.40)	9.00 (5.60–13.0)	2,489
	2013–2014	0.669 (0.603–0.743)	0.600 (0.500–0.700)	1.30 (1.20–1.40)	3.00 (2.70–3.50)	6.40 (4.80–11.5)	2,686
	2015-2016	0.596 (.509-.698)	500 (.500-.600)	1.30(1.10-1.70)	3.80 (2.90-4.70)	7.70 (5.20-11.7)	2,651
Age group							
Age 3–5 years	2015–2016	0.493 (0.381–0.636)	0.400 (0.300–0.500)	0.800 (0.600–1.30)	2.50 (1.30–7.10)	7.80 (2.50–16.9)	141
Age 6–11 years	2003–2004	1.01 (0.796–1.28)	0.800 (0.600–1.20)	2.30 (1.70–3.20)	7.70 (3.80–20.1)	23.5 (9.40–31.0)	314
	2005–2006	1.01 (0.879–1.15)	0.800 (0.800–1.10)	2.00 (1.60–2.30)	4.90 (3.30–6.60)	9.80 (6.30–17.6)	356
	2007–2008	1.04 (0.778–1.39)	0.900 (0.700–1.20)	1.80 (1.20–2.80)	5.90 (2.90–10.1)	11.4 (6.60–20.7)	389
	2009–2010	0.975 (0.768–1.24)	0.700 (0.600–0.900)	1.80 (1.40–2.30)	5.00 (3.20–8.40)	14.2 (4.40–90.9)	415
	2011–2012	0.672 (0.558–0.810)	0.600 (0.400–0.700)	1.10 (1.00–1.40)	3.60 (1.90–5.50)	11.3 (4.10–23.2)	396
	2013–2014	0.773 (0.646–0.925)	0.700 (0.600–0.900)	1.20 (1.10–1.60)	2.90 (2.10–4.80)	8.90 (3.30–21.8)	409
	2015–2016	0.681 (0.510–0.909)	0.600 (0.400–0.800)	1.30 (1.00–2.00)	4.60 (2.20–7.10)	8.50 (4.80–15.0)	415
Age 12–19 years	2003–2004	1.27 (0.971–1.67)	1.10 (0.800–1.50)	3.40 (2.50–5.00)	13.6 (6.10–25.5)	31.5 (14.5–85.0)	722
	2005–2006	1.18 (0.997–1.39)	1.00 (0.900–1.20)	2.50 (2.00–3.10)	5.50 (4.00–8.30)	13.9 (7.10–33.6)	702
	2007–2008	1.19 (0.989–1.44)	1.10 (0.800–1.40)	2.60 (2.00–3.00)	5.60 (3.10–10.8)	11.6 (5.70–36.5)	401
	2009–2010	0.967 (0.794–1.18)	0.800 (0.700–0.900)	1.60 (1.40–2.70)	5.80 (3.70–10.1)	14.4 (7.10–24.8)	420
	2011–2012	0.711 (0.591–0.857)	0.600 (0.500–0.800)	1.30 (1.00–1.50)	3.30 (2.10–5.80)	9.00 (4.10–13.0)	388
	2013–2014	0.668 (0.576–0.775)	0.600 (0.500–0.700)	1.10 (0.900–1.40)	2.40 (1.70–4.40)	7.30 (3.10–13.8)	462
	2015–2016	0.819 (0.631–1.06)	0.700(0.500–1.00)	1.90 (1.5–2.60)	5.80 (4.50–8.40)	10.8 (6.30–22.4)	405
Age 20+ years	2003–2004	1.01 (0.874–1.17)	0.900 (0.700–1.10)	2.60 (2.20–3.00)	8.50 (6.60–10.4)	19.4 (12.2–27.0)	1,489
	2005–2006	0.907 (0.737–1.12)	0.800 (0.600–1.00)	2.00 (1.50–2.40)	4.90 (3.70–6.40)	11.1 (6.50–20.9)	1,490
	2007–2008	0.932 (0.820–1.06)	0.800 (0.700–0.900)	1.70 (1.40–2.20)	5.00 (3.80–7.60)	13.2 (9.20–18.1)	1,814
	2009–2010	0.764 (0.699–0.836)	0.700 (0.600–0.700)	1.40 (1.30–1.60)	3.60 (3.10–4.50)	8.00 (5.60–13.9)	1,914
	2011–2012	0.695 (0.613–0.789)	0.600 (0.500–0.700)	10.30 (10.10–1.60)	3.50 (2.80–4.60)	9.00 (5.20–13.1)	1,705
	2013–2014	0.659 (0.593–0.732)	0.600 (0.500–0.700)	1.30 (1.20–1.40)	3.10 (2.70–3.50)	6.20 (4.90–10.8)	1,815
	2015–2016	0.562 (0.481–0.657)	0.500 (.500–0.600)	1.30 (1.00–1.60)	3.40 (2.60–4.30)	7.40 (4.50–11.7)	1,690

Table 5-8. Geometric Mean and Selected Percentiles of Urinary 2,4-Dichlorophenol Concentrations (in µg/L) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES) 2003–2016

	Survey years[a]	Geometric mean (95% CI)	Selected percentiles (95% CI)				Sample size
			50th	75th	90th	95th	
Gender							
Males	2003–2004	1.22 (1.02–1.45)	1.10 (0.800–1.50)	3.00 (2.50–3.50)	9.40 (6.80–13.9)	22.7 (13.6–40.9)	1,231
	2005–2006	1.16 (0.973–1.37)	1.00 (0.900–1.20)	2.40 (2.00–2.80)	5.50 (4.40–7.90)	12.9 (7.30–25.3)	1,270
	2007–2008	1.06 (0.943–1.19)	0.900 (0.800–1.00)	1.90 (1.60–2.20)	5.40 (3.90–8.20)	13.6 (10.1–18.1)	1,294
	2009–2010	0.879 (0.789–0.979)	0.800 (0.700–0.800)	1.60 (1.40–1.80)	4.00 (3.20–5.70)	10.4 (5.20–18.4)	1,399
	2011–2012	0.717 (0.641–0.802)	0.600 (0.600–0.700)	1.30 (1.10–1.60)	3.20 (2.20–4.40)	7.10 (4.60–10.6)	1,259
	2013–2014	0.708 (0.637–0.786)	0.600 (0.600–0.700)	1.30 (1.10–1.60)	2.90 (2.60–3.30)	6.20 (4.10–11.3)	1,285
	2015–2016	0.613 (0.532–0.705)	0.500 (0.500–0.600)	1.30 (1.00–1.70)	3.60 (2.60–4.30)	7.70 (4.40–12.3)	1,307
Females	2003–2004	0.896 (0.754–1.07)	0.800 (0.600–0.900)	2.30 (2.00–2.70)	8.10 (5.70–11.1)	19.8 (12.0–27.5)	1,294
	2005–2006	0.779 (0.637–0.954)	0.700 (0.500–0.800)	1.50 (1.30–2.10)	4.30 (2.80–6.20)	9.40 (5.40–19.6)	1,278
	2007–2008	0.893 (0.750–1.06)	0.700 (0.600–0.800)	1.80 (1.20–2.50)	4.70 (3.10–8.00)	11.9 (7.60–18.6)	1,310
	2009–2010	0.737 (0.659–0.824)	0.600 (0.600–0.700)	1.40 (1.30–1.70)	4.00 (3.00–5.50)	7.80 (5.80–15.8)	1,350
	2011–2012	0.675 (0.581–0.784)	0.600 (0.500–0.700)	1.20 (1.00–1.60)	3.80 (2.80–6.00)	11.1 (4.90–24.3)	1,230
	2013–2014	0.635 (0.553–0.729)	0.600 (0.500–0.700)	1.20 (1.10–1.40)	3.10 (2.50–4.10)	7.60 (4.40–12.3)	1,401
	2015–2016	0.580 (0.466–0.721)	0.500 (0.400–0.600)	1.40 (1.00–1.80)	4.20 (2.90–5.80)	8.10 (5.70–14.5)	1,344
Race/ethnicity							
Mexican Americans	2003–2004	1.94 (1.46–2.56)	1.70 (1.20–2.10)	4.50 (2.80–9.30)	26.9 (12.7–52.1)	66.0 (47.5–84.2)	617
	2005–2006	1.97 (1.49–2.59)	1.60 (1.20–2.10)	5.00 (3.30–6.60)	20.9 (8.80–39.7)	46.5 (21.9–79.5)	637
	2007–2008	1.59 (0.969–2.60)	1.20 (0.600–2.60)	4.20 (2.10–9.50)	13.4 (7.90–29.6)	38.0 (16.4–74.0)	531
	2009–2010	1.25 (0.860–1.81)	0.900 (0.700–1.30)	2.70 (1.60–4.30)	11.3 (4.30–26.3)	29.1 (7.60–76.3)	566
	2011–2012	0.895 (0.720–10.11)	0.800 (0.600–10.00)	1.80 (1.30–2.60)	6.60 (3.50–10.5)	14.5 (7.40–27.0)	316
	2013–2014	0.807 (0.609–10.07)	0.600 (0.400–10.00)	1.70 (1.10–2.90)	4.00 (3.00–12.2)	14.6 (3.90–49.9)	438
	2015–2016	0.970 (0.706–1.33)	0.800 (0.500–1.10)	2.40 (1.40–4.80)	9.20 (6.30–14.5)	17.1 (11.3–23.4)	513
Non–Hispanic blacks	2003–2004	2.42 (1.92–3.06)	2.20 (1.70–2.70)	7.40 (4.00–9.60)	20.8 (11.2–38.3)	49.2 (24.0–69.7)	636
	2005–2006	2.45 (1.93–3.12)	2.10 (1.70–2.40)	5.20 (3.90–7.40)	20.3 (10.6–36.9)	42.6 (21.3–129)	678
	2007–2008	1.73 (1.49–2.01)	1.40 (1.10–1.60)	3.70 (2.90–4.90)	17.8 (9.70–25.8)	37.7 (24.6–56.8)	597
	2009–2010	1.54 (1.06–2.23)	1.20 (0.800–2.00)	3.10 (2.10–4.80)	12.4 (4.30–46.4)	35.2 (7.80–107)	516
	2011–2012	10.23 (0.965–10.57)	0.900 (0.800–10.20)	2.20 (1.60–3.30)	6.90 (4.20–14.8)	25.0 (8.40–53.6)	665
	2013–2014	10.11 (0.791–10.54)	0.800 (0.700–10.10)	2.00 (1.40–3.30)	8.20 (3.00–28.2)	23.5 (6.50–81.9)	609
	2015–2016	1.42 (.986–2.04)	1.10(0.800–1.50)	3.00 (2.10–5.00)	16.0 (6.10–50.6)	55.5 (20.7–153)	610

Table 5-8. Geometric Mean and Selected Percentiles of Urinary 2,4-Dichlorophenol Concentrations (in µg/L) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES) 2003–2016

	Survey years[a]	Geometric mean (95% CI)	Selected percentiles (95% CI)				Sample size
			50th	75th	90th	95th	
Non–Hispanic whites	2003–2004	0.837 (0.698–1.00)	0.700 (0.600–0.900)	2.10 (1.70–2.60)	6.20 (4.00–8.80)	13.4 (8.60–22.0)	1,077
	2005–2006	0.734 (0.610–0.883)	0.700 (0.500–0.900)	1.40 (1.20–1.80)	3.10 (2.70–3.90)	5.30 (4.30–7.90)	1,038
	2007–2008	0.817 (0.732–0.911)	0.700 (0.600–0.800)	1.50 (1.20–1.80)	3.10 (2.60–4.40)	6.40 (4.60–8.80)	1,077
	2009–2010	0.651 (0.594–0.712)	0.600 (0.500–0.700)	1.30 (1.10–1.40)	2.80 (2.20–3.50)	5.60 (3.80–7.40)	1,206
	2011–2012	0.577 (0.514–0.647)	0.500 (0.500–0.600)	1.00 (0.900–1.20)	2.50 (1.70–3.70)	4.90 (3.30–9.40)	813
	2013–2014	0.588 (0.525–0.659)	0.500 (0.500–0.600)	1.10 (1.00–1.30)	2.60 (2.30–2.90)	4.60 (3.10–5.50)	988
	2015–2016	0.458 (0.397–0.528)	0.400 (0.400–0.500)	1.00 (0.800–1.30)	2.40 (1.90–3.10)	4.20 (3.20–5.10)	781
All Hispanics	2011–2012	0.981 (0.760–10.27)	0.800 (0.600–10.00)	2.10 (1.30–3.10)	6.10 (3.90–13.0)	15.9 (7.00–42.0)	571
	2013–2014	0.786 (0.641–0.965)	0.600 (0.500–0.800)	1.60 (1.20–2.10)	3.50 (3.10–7.80)	12.4 (4.20–26.1)	690
	2015–2016	0.982 (0.757–1.27)	0.800 (0.600–1.10)	2.40 (1.60–3.60)	9.00 (5.40–15.0)	17.7 (10.5–30.1)	859
Asians	2011–2012	0.621 (0.478–0.807)	0.500 (0.400–0.700)	1.10 (0.800–1.60)	3.60 (1.70–7.10)	11.1 (3.50–17.7)	352
	2013–2014	0.567 (0.435–0.738)	0.500 (0.300–0.700)	1.20 (0.800–1.60)	2.70 (1.70–5.80)	7.30 (2.50–58.9)	289
	2015–2016	0.466 (0.364–0.596)	0.400 (0.300–0.600)	1.00 (0.800–1.30)	2.30 (1.80–5.40)	6.50 (2.20–10.8)	275

[a] The LODs for survey years 2003–2004, 2005–2006, 2007–2008, 2009–2010, 2011–2012, 2013–2104, and 2015-2016 are 0.17, 0.2, 0.2, 0.2, 0.2, 0.1, and 0.1, respectively.

CI = confidence interval; LOD = limit of detection

Source: CDC 2019, 2021

Table 5-9. Geometric Mean and Selected Percentiles of Urinary 2,4-Dichlorophenol Concentrations (Creatinine Corrected) (in µg/g of Creatinine) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES) 2003–2016

	Survey years[a]	Geometric mean (95% CI)	Selected percentiles (95% CI)				Sample size
			50th	75th	90th	95th	
Total population	2003–2004	1.02 (0.873–1.18)	0.880 (0.770–1.00)	2.19 (1.84–2.73)	7.39 (5.00–9.83)	15.4 (11.1–20.9)	2,522
	2005–2006	0.922 (0.798–1.06)	0.750 (0.660–0.880)	1.58 (1.33–1.86)	4.00 (3.00–5.71)	8.90 (5.98–16.6)	2,548
	2007–2008	0.978 (0.867–1.10)	0.790 (0.700–0.880)	1.63 (1.36–1.89)	4.00 (3.14–5.63)	11.7 (6.82–18.9)	2,604
	2009–2010	0.838 (0.757–0.929)	0.680 (0.630–0.740)	1.33 (1.18–1.58)	3.48 (2.77–4.55)	8.17 (5.44–14.3)	2,749
	2011–2012	0.791 (0.706–0.886)	0.614 (0.560–0.690)	1.29 (1.08–1.48)	3.33 (2.67–4.57)	8.10 (5.65–11.2)	2,487
	2013–2014	0.668 (0.611–0.730)	0.556 (0.510–0.595)	1.13 (1.03–1.29)	2.73 (2.26–3.33)	5.96 (4.41–8.38)	2,684
	2015–2016	0.605 (0.524–0.699)	0.467 (0.421–0.537)	1.14 (0.900–1.48)	3.02 (2.22–3.99)	6.08 (4.18–-9.53)	2,650
Age group							
Age 3–5 years	2015–2016	1.16 (.921–1.46)	0.833 (0.682–1.21)	1.92 (1.36–2.55)	4.44 (2.81–14.9)	17.2 (4.28–50.0)	140
Age 6–11 years	2003–2004	1.23 (0.965–1.56)	1.03 (0.750–1.45)	2.39 (1.82–3.36)	9.29 (3.98–16.5)	20.9 (12.9–38.1)	314
	2005–2006	1.11 (0.950–1.29)	0.970 (0.800–1.08)	1.74 (1.38–2.19)	4.38 (3.33–7.80)	10.9 (5.12–23.3)	356
	2007–2008	1.28 (1.00–1.63)	1.06 (0.750–1.40)	2.06 (1.44–3.21)	4.49 (3.13–9.27)	11.2 (5.70–24.4)	389
	2009–2010	1.27 (0.986–1.64)	0.930 (0.820–1.20)	2.03 (1.54–2.94)	5.89 (3.50–11.0)	15.9 (5.71–121)	415
	2011–2012	0.964 (0.807–1.15)	0.741 (0.620–0.851)	1.38 (1.07–1.61)	3.51 (2.22–7.36)	12.4 (5.13–34.9)	395
	2013–2014	0.977 (0.833–1.14)	0.800 (0.698–0.909)	1.52 (1.20–1.94)	3.41 (2.22–6.60)	9.68 (4.48–23.7)	409
	2015–2016	0.877 (0.683–1.13)	0.727 (0.541–0.851)	1.60 (1.05–2.31)	4.25 (2.40–9.84)	10.0 (4.14–17.4)	415
Age 12–19 years	2003–2004	0.954 (0.725–1.26)	0.790 (0.660–1.00)	2.08 (1.44–3.75)	8.02 (4.72–12.5)	14.8 (8.02–40.0)	720
	2005–2006	0.878 (0.765–1.01)	0.700 (0.600–0.800)	1.65 (1.22–1.93)	3.92 (2.90–4.82)	8.28 (4.82–15.9)	702
	2007–2008	0.927 (0.776–1.11)	0.790 (0.640–1.00)	1.51 (1.14–2.22)	3.81 (2.38–5.92)	10.3 (4.28–21.8)	401
	2009–2010	0.778 (0.656–0.921)	0.580 (0.510–0.690)	1.18 (0.970–1.40)	3.38 (2.11–6.27)	7.38 (3.39–19.4)	420
	2011–2012	0.693 (0.582–0.825)	0.545 (0.465–0.678)	1.15 (0.875–1.50)	2.73 (1.96–4.00)	4.82 (3.06–9.75)	388
	2013–2014	0.542 (0.472–0.623)	0.439 (0.385–0.519)	0.833 (0.678–1.13)	1.72 (1.31–3.08)	4.10 (2.45–5.27)	462
	2015–2016	0.636 (0.523–0.774)	0.457 (0.382–0.550)	1.29 (0.875–1.75)	3.66 (2.86–5.43)	7.03 (4.00–21.3)	405
Age 20+ years	2003–2004	1.00 (0.863–1.16)	0.870 (0.770–1.00)	2.17 (1.80–2.69)	7.16 (4.88–9.01)	15.0 (10.6–20.8)	1,488
	2005–2006	0.909 (0.774–1.07)	0.740 (0.650–0.870)	1.55 (1.25–1.89)	4.00 (2.84–6.19)	8.80 (5.71–16.8)	1,490
	2007–2008	0.958 (0.847–1.08)	0.770 (0.670–0.880)	1.60 (1.32–1.85)	3.98 (3.14–5.59)	12.1 (8.15–18.9)	1,814
	2009–2010	0.810 (0.735–0.892)	0.670 (0.620–0.730)	1.27 (1.11–1.56)	3.33 (2.65–4.23)	7.64 (5.16–12.3)	1,914
	2011–2012	0.790 (0.694–0.898)	0.610 (0.556–0.675)	1.30 (1.07–1.54)	3.33 (2.55–4.77)	8.33 (5.75–11.3)	1,704
	2013–2014	0.661 (0.600–0.728)	0.538 (0.495–0.588)	1.14 (0.991–1.31)	2.77 (2.22–3.47)	5.96 (4.39–8.53)	1,813
	2015–2016	0.573 (0.498–0.659)	0.446 (0.404–0.513)	1.08 (0.854–1.42)	2.71 (2.03–3.88)	5.80 (3.85–8.51)	1,690

Table 5-9. Geometric Mean and Selected Percentiles of Urinary 2,4-Dichlorophenol Concentrations (Creatinine Corrected) (in µg/g of Creatinine) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES) 2003–2016

	Survey years[a]	Geometric mean (95% CI)	Selected percentiles (95% CI)				Sample size
			50th	75th	90th	95th	
Gender							
Males	2003–2004	0.995 (0.850–1.17)	0.900 (0.730–1.06)	2.23 (1.82–2.82)	6.84 (4.54–9.01)	13.7 (9.29–21.8)	1,230
	2005–2006	0.927 (0.814–1.06)	0.770 (0.670–0.880)	1.60 (1.36–1.86)	4.12 (3.08–5.45)	8.90 (5.19–16.6)	1,270
	2007–2008	0.891 (0.808–0.984)	0.720 (0.660–0.790)	1.44 (1.29–1.67)	4.00 (2.97–5.30)	9.96 (6.82–13.4)	1,294
	2009–2010	0.788 (0.706–0.879)	0.620 (0.580–0.660)	1.25 (1.06–1.48)	3.66 (2.52–5.47)	7.69 (4.84–16.9)	1,399
	2011–2012	0.670 (0.594–0.756)	0.538 (0.462–0.609)	1.08 (0.903–1.27)	2.89 (2.10–3.46)	5.65 (4.26–7.63)	1,258
	2013–2014	0.595 (0.550–0.642)	0.496 (0.455–0.538)	1.03 (0.906–1.12)	2.41 (2.11–2.77)	4.39 (3.06–7.65)	1,284
	2015–2016	0.534 (0.471–0.607)	0.424 (0.380–0.476)	0.957 (0.811–1.18)	2.67 (1.75–3.53)	4.95 (3.60–8.44)	1,307
Females	2003–2004	1.03 (0.845–1.27)	0.870 (0.770–1.00)	2.17 (1.73–2.73)	8.00 (4.57–12.1)	17.2 (11.1–23.7)	1,292
	2005–2006	0.916 (0.770–1.09)	0.740 (0.640–0.880)	1.56 (1.19–1.96)	3.91 (2.66–6.50)	8.93 (5.53–23.7)	1,278
	2007–2008	1.07 (0.910–1.26)	0.850 (0.720–1.00)	1.75 (1.43–2.29)	4.07 (3.13–7.65)	14.4 (6.50–26.8)	1,310
	2009–2010	0.890 (0.789–1.00)	0.740 (0.660–0.850)	1.41 (1.24–1.67)	3.39 (2.76–4.52)	8.79 (5.16–14.8)	1,350
	2011–2012	0.928 (0.816–1.06)	0.714 (0.634–0.833)	1.45 (1.27–1.76)	4.02 (3.06–6.37)	11.2 (6.37–18.1)	1,229
	2013–2014	0.747 (0.667–0.836)	0.616 (0.560–0.676)	1.29 (1.11–1.43)	3.29 (2.37–4.15)	7.69 (4.69–12.6)	1,400
	2015–2016	0.682 (0.568–0.820)	0.526 (0.450–0.625)	1.32 (0.915–1.82)	3.66 (2.40–5.65)	6.48 (4.55–13.0)	1,343
Race/ethnicity							
Mexican Americans	2003–2004	1.76 (1.30–2.38)	1.33 (1.04–1.74)	3.85 (2.29–8.81)	23.8 (10.6–51.6)	71.4 (30.8–88.8)	616
	2005–2006	1.77 (1.38–2.27)	1.25 (0.990–1.73)	3.79 (2.70–5.35)	16.6 (6.75–31.8)	38.1 (23.8–55.3)	637
	2007–2008	1.55 (0.925–2.60)	1.18 (0.630–2.28)	3.33 (1.93–6.50)	14.2 (5.65–30.6)	33.1 (16.6–60.0)	531
	2009–2010	1.24 (0.860–1.78)	0.910 (0.630–1.28)	2.03 (1.43–3.90)	11.0 (3.54–26.4)	26.4 (10.2–93.5)	566
	2011–2012	1.01 (0.856–1.19)	0.788 (0.620–1.04)	1.67 (1.50–2.14)	5.94 (3.50–9.36)	14.7 (6.16–33.3)	316
	2013–2014	0.823 (0.614–1.10)	0.632 (0.452–0.864)	1.43 (0.938–2.29)	6.25 (2.45–12.0)	13.5 (6.32–37.3)	438
	2015–2016	1.02 (0.740–1.40)	0.727 (0.500–1.13)	2.31 (1.50–3.93)	7.73 (5.65–12.5)	19.7 (10.0–35.1)	513
Non-Hispanic blacks	2003–2004	1.66 (1.28–2.16)	1.47 (1.06–1.96)	4.14 (2.46–7.31)	14.9 (7.93–20.1)	22.9 (16.7–45.0)	635
	2005–2006	1.72 (1.39–2.14)	1.32 (1.11–1.56)	3.28 (2.33–5.35)	14.9 (7.40–28.1)	37.0 (15.0–83.4)	678
	2007–2008	1.34 (1.14–1.59)	0.990 (0.800–1.17)	2.36 (1.85–3.12)	13.1 (5.70–23.3)	33.8 (22.7–41.1)	597
	2009–2010	1.11 (0.739–1.67)	0.890 (0.630–1.19)	2.07 (1.25–3.87)	8.37 (2.99–22.0)	22.0 (7.05–83.1)	516
	2011–2012	0.959 (0.766–1.20)	0.737 (0.588–0.851)	1.56 (1.18–2.34)	5.26 (3.00–15.0)	19.9 (6.61–40.7)	665
	2013–2014	0.815 (0.617–1.08)	0.576 (0.500–0.704)	1.40 (0.952–2.30)	5.32 (2.37–14.7)	15.4 (4.69–51.3)	609
	2015–2016	1.1 (0.798–1.51)	0.760 (0.538–1.15)	2.17 (1.59–2.99)	11.2 (4.00–38.0)	59.8 (11.8–133)	609

Table 5-9. Geometric Mean and Selected Percentiles of Urinary 2,4-Dichlorophenol Concentrations (Creatinine Corrected) (in µg/g of Creatinine) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES) 2003–2016

	Survey years[a]	Geometric mean (95% CI)	Selected percentiles (95% CI)				Sample size
			50th	75th	90th	95th	
Non-Hispanic whites	2003–2004	0.864 (0.721–1.03)	0.780 (0.690–0.890)	1.86 (1.54–2.23)	5.08 (3.58–8.00)	10.8 (6.84–18.2)	1,076
	2005–2006	0.772 (0.660–0.904)	0.670 (0.580–0.790)	1.25 (1.07–1.56)	2.78 (2.11–3.52)	4.82 (3.33–8.62)	1,038
	2007–2008	0.853 (0.765–0.950)	0.730 (0.660–0.810)	1.36 (1.14–1.67)	2.97 (2.53–3.33)	5.16 (3.84–9.38)	1,077
	2009–2010	0.731 (0.674–0.793)	0.630 (0.580–0.690)	1.13 (1.01–1.25)	2.76 (2.29–3.30)	5.16 (3.79–6.46)	1,206
	2011–2012	0.700 (0.609–0.805)	0.563 (0.519–0.619)	1.08 (0.885–1.33)	2.89 (1.79–3.78)	5.75 (3.27–9.67)	811
	2013–2014	0.615 (0.557–0.679)	0.521 (0.476–0.570)	1.05 (0.906–1.24)	2.22 (1.88–2.78)	3.64 (3.01–5.71)	987
	2015–2016	0.485 (0.435–0.541)	0.408 (0.380–0.444)	0.870 (0.758–1.00)	1.82 (1.49–2.63)	3.60 (2.61–4.72)	781
All Hispanics	2011–2012	1.10 (0.919–1.31)	0.870 (0.700–1.12)	2.00 (1.54–2.72)	5.70 (3.96–9.26)	14.7 (6.37–43.5)	571
	2013–2014	0.780 (0.628–0.970)	0.629 (0.508–0.774)	1.30 (0.980–1.98)	4.48 (3.03–6.81)	11.1 (6.16–23.8)	690
	2015–2016	1 (0.755–1.33)	0.772 (0.543–1.08)	2.14 (1.58–3.44)	7.20 (5.30–12.5)	17.4 (9.16–37.2)	859
Asians	2011–2012	0.832 (0.629–1.10)	0.667 (0.513–0.952)	1.42 (1.01–2.12)	3.50 (2.31–7.82)	8.00 (3.50–17.0)	352
	2013–2014	0.720 (0.540–0.961)	0.588 (0.469–0.813)	1.38 (1.06–1.71)	3.51 (1.95–6.78)	7.65 (2.54–54.1)	288
	2015–2016	0.567 (0.473–0.680)	0.455 (0.385–0.533)	1.05 (0.845–1.67)	3.43 (2.19–4.66)	5.44 (4.17–7.65)	275

[a] The LODs for survey years 2003–2004, 2005–2006, 2007–2008, 2009–2010, 2011–2012, 2013–2104, and 2015-2016 are 0.17, 0.2, 0.2, 0.2, 0.2, 0.1, and 0.1 respectively.

CI = confidence interval; LOD = limit of detection

Source: CDC 2019, 2021

Table 5-10. Geometric Mean and Selected Percentiles of Urinary 2,5-Dichlorophenol Concentrations (in µg/L) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES) 2003–2016

	Survey years[a]	Geometric mean (95% CI)	Selected percentiles (95% CI) 50th	75th	90th	95th	Sample size
Total population	2003–2004	12.9 (10.1–16.3)	10.5 (8.00–14.2)	40.9 (29.8–54.7)	190 (133–282)	705 (342–1,330)	2,525
	2005–2006	9.55 (6.67–13.7)	8.10 (5.60–11.5)	26.4 (19.0–36.6)	111 (69.9–166)	332 (175–794)	2,548
	2007–2008	9.04 (7.22–11.3)	6.60 (5.50–8.30)	25.7 (19.2–34.7)	131 (90.2–222)	473 (296–753)	2,604
	2009–2010	6.10 (4.94–7.53)	4.70 (3.70–5.90)	18.4 (13.3–26.0)	101 (68.0–146)	301 (168–618)	2,749
	2011–2012	4.21 (3.15–5.62)	3.10 (2.30–3.90)	13.4 (9.40–18.9)	69.9 (40.9–117)	213 (121–404)	2,489
	2013–2014	2.78 (2.15–3.59)	1.80 (1.40–2.50)	7.50 (5.30–11.4)	37.7 (23.8–58.0)	148 (78.4–266)	2,686
	2015–2016	2.97 (2.19–4.02)	2.10 (1.60–2.80)	9.30 (5.70–16.3)	51.0 (29.3–103)	175 (95.9–358)	2,651
Age group							
Age 3–5 years	2015–2016	2.53 (1.45–4.43)	1.60 (.800–3.10)	8.00 (2.80–18.2)	35.6 (15.0–76.8)	262 (35.6–573)	141
Age 6–11 years	2003–2004	12.5 (8.22–18.9)	9.10 (5.60–17.4)	42.1 (21.7–83.9)	161 (111–626)	928 (249–1,640)	314
	2005–2006	10.5 (8.29–13.4)	7.80 (5.90–10.6)	28.1 (17.8–40.2)	104 (55.4–226)	336 (189–785)	356
	2007–2008	9.31 (6.20–14.0)	6.50 (4.60–10.9)	23.3 (12.2–45.6)	151 (61.1–306)	464 (222–934)	389
	2009–2010	7.19 (4.36–11.8)	4.80 (2.70–9.90)	30.4 (12.4–50.7)	146 (63.7–368)	503 (103–4,940)	415
	2011–2012	3.45 (2.11–5.64)	2.30 (1.60–3.30)	9.20 (4.40–21.2)	69.1 (27.8–168)	369 (99.9–986)	396
	2013–2014	2.90 (1.98–4.24)	2.00 (1.30–3.00)	8.20 (4.30–14.9)	29.6 (19.7–73.8)	123 (38.0–438)	409
	2015–2016	3.82 (2.21–6.58)	2.70 (1.40–5.30)	14.4 (5.60–36.5)	73.4 (35.8–189)	196 (83.4–343)	415
Age 12–19 years	2003–2004	16.9 (11.1–26.0)	11.5 (8.20–20.6)	49.9 (26.8–94.0)	233 (94.5–1,060)	1,080 (287–3,970)	722
	2005–2006	11.9 (8.47–16.8)	9.60 (6.40–16.7)	36.0 (22.3–54.4)	127 (89.9–160)	459 (160–894)	702
	2007–2008	11.3 (8.78–14.5)	7.40 (6.20–9.10)	30.1 (18.5–52.6)	193 (66.7–448)	611 (254–1,560)	401
	2009–2010	8.01 (5.53–11.6)	4.80 (3.50–8.80)	24.9 (19.1–42.7)	191 (61.2–368)	526 (243–1,140)	420
	2011–2012	4.15 (2.43–7.10)	3.20 (1.60–8.00)	14.0 (7.30–28.8)	55.7 (28.6–209)	236 (71.2–468)	388
	2013–2014	2.72 (1.75–4.24)	2.10 (1.30–3.30)	6.00 (3.80–14.0))	21.7 (10.6–77.7)	77.7 (21.7–315)	462
	2015–2016	5.12 (3.40–7.71)	3.30 (2.30–6.80)	17.6 (10.3–36.1	125 (66.7–210)	373 (207–711)	405
Age 20+ years	2003–2004	12.3 (9.97–15.3)	10.4 (8.00–14.0)	40.5 (30.1–49.2)	181 (141–250)	583 (316–924)	1,489
	2005–2006	9.12 (6.15–13.5)	7.80 (5.20–11.5)	24.9 (17.3–35.3)	110 (62.9–183)	327 (159–852)	1,490
	2007–2008	8.71 (6.83–11.1)	6.60 (5.10–8.70)	24.6 (18.8–34.5)	124 (95.9–186)	452 (286–672)	1,814
	2009–2010	5.75 (4.77–6.92)	4.60 (3.70–5.70)	16.9 (12.7–23.1)	88.4 (66.4–117)	266 (156–450)	1,914
	2011–2012	4.31 (3.21–5.78)	3.20 (2.30–4.10)	14.2 (9.40–19.2)	71.4 (39.5–118)	198 (118–408)	1,705
	2013–2014	2.78 (2.20–3.51)	1.80 (1.40–2.40)	7.80 (5.50–11.5)	42.7 (25.2–61.2)	169 (87.2–308)	1,815
	2015–2016	2.68 (1.97–3.64)	1.90 (1.50–2.50)	7.90 (5.00–13.4)	40.9 (21.7–99.0)	164 (73.5–352)	1,690

Table 5-10. Geometric Mean and Selected Percentiles of Urinary 2,5-Dichlorophenol Concentrations (in µg/L) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES) 2003–2016

			Selected percentiles (95% CI)				
	Survey years[a]	Geometric mean (95% CI)	50th	75th	90th	95th	Sample size
Gender							
Males	2003–2004	14.9 (11.8–18.8)	12.5 (9.00–16.5)	40.5 (30.7–54.5)	152 (120–259)	631 (259–1,950)	1,231
	2005–2006	12.0 (8.55–16.7)	9.90 (7.80–13.8)	29.0 (21.8–40.5)	114 (71.7–200)	396 (175–916)	1,270
	2007–2008	10.9 (8.86–13.4)	8.30 (6.30–9.90)	29.4 (23.2–39.6)	139 (100–248)	546 (311–727)	1,294
	2009–2010	7.09 (5.68–8.85)	5.30 (4.40–6.70)	21.9 (15.2–33.5)	103 (63.3–191)	311 (133–736)	1,399
	2011–2012	4.42 (3.38–5.78)	3.30 (2.40–4.50)	13.2 (9.40–20.8)	55.5 (37.1–106)	194 (99.8–341)	1,259
	2013–2014	2.96 (2.31–3.80)	2.00 (1.50–2.60)	7.20 (5.20–11.5)	36.1 (23.1–52.6)	175 (77.6–250)	1,285
	2015–2016	3.25 (2.41–4.38)	2.40 (1.70–3.10)	9.90 (6.30–16.6)	44.9 (24.0–99.0)	159 (80.8–358)	1,307
Females	2003–2004	11.2 (8.51–14.7)	8.50 (6.30–12.0)	42.8 (26.0–64.2)	212 (141–364)	732 (371–1,100)	1,294
	2005–2006	7.69 (5.17–11.4)	5.90 (3.90–9.40)	21.1 (14.3–35.7)	110 (60.5–183)	317 (141–794)	1,278
	2007–2008	7.57 (5.70–10.1)	5.50 (4.40–7.30)	20.6 (13.9–31.8)	118 (57.4–268)	442 (213–838)	1,310
	2009–2010	5.28 (4.17–6.69)	3.90 (3.00–5.10)	16.7 (12.1–22.1)	99.5 (58.2–156)	287 (158–591)	1,350
	2011–2012	4.01 (2.86–5.61)	2.80 (2.00–3.70)	13.9 (9.20–17.7)	83.3 (42.4–124)	352 (117–614)	1,230
	2013–2014	2.61 (1.96–3.48)	1.70 (1.30–2.50)	7.80 (5.20–11.9)	38.3 (21.6–63.8)	136 (63.2–376))	1,401
	2015–2016	2.72 (1.90–3.90)	1.80 (1.40–2.50)	8.40 (4.80–17.6)	51.9 (31.6–140)	199 (89.4–373)	1,344
Race/ethnicity							
Mexican Americans	2003–2004	30.1 (19.2–47.2)	23.7 (14.7–39.8)	103 (57.4–156)	841 (282–2,040)	2,370 (2,040–3,710)	617
	2005–2006	32.2 (22.2–46.7)	23.0 (14.9–37.1)	120 (69.6–228)	867 (298–1,320)	1,630 (916–3,650)	637
	2007–2008	22.2 (9.88–49.8)	16.4 (5.40–60.7)	104 (35.2–364)	566 (313–1,710)	1,920 (672–3,460)	531
	2009–2010	13.0 (5.80–29.1)	10.3 (3.30–26.2)	53.6 (19.4–199)	361 (124–900)	998 (247–3,700)	566
	2011–2012	5.92 (3.36–10.4)	4.00 (2.20–8.40)	21.2 (14.2–42.7)	178 (58.4–341)	362 (119–1,130)	316
	2013–2014	4.60 (2.78–7.61)	2.70 (1.40–6.30)	14.5 (6.70–29.2)	90.5 (32.9–486)	584 (85.3–1,840)	438
	2015–2016	9.27 (4.65–18.5)	7.20 (3.00–18.6)	33.6 (13.8–124)	310 (118–462)	633 (428–930)	513
Non-Hispanic blacks	2003–2004	54.0 (35.9–81.2)	43.9 (26.2–65.6)	159 (97.0–338)	817 (342–2,330)	2,330 (887–3,730)	636
	2005–2006	43.9 (33.2–58.1)	33.2 (25.3–47.6)	161 (79.9–255)	722 (360–1,370)	1,700 (886–6,440)	678
	2007–2008	27.4 (21.3–35.2)	18.5 (13.2–26.7)	102 (61.9–147)	682 (364–943)	1,490 (933–1,870)	597
	2009–2010	23.0 (13.0–40.8)	17.3 (8.00–42.7)	82.7 (38.6–168)	443 (119–2,180)	1,240 (273–4,940)	516
	2011–2012	16.6 (10.4–26.2)	13.4 (8.80–19.4)	47.9 (24.9–100)	227 (108–569)	759 (341–2,480)	665
	2013–2014	9.58 (5.03–18.2)	7.20 (3.90–14.2)	27.6 (15.6–70.7)	175 (51.4–874)	843 (150–3,710)	609
	2015–2016	18.1 (10.4–31.4)	12.7 (7.20–25.9)	69.9 (38.4–150)	503 (175–1,940)	2,210 (768–6,510)	610

Table 5-10. Geometric Mean and Selected Percentiles of Urinary 2,5-Dichlorophenol Concentrations (in µg/L) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES) 2003–2016

	Survey years[a]	Geometric mean (95% CI)	Selected percentiles (95% CI)				Sample size
			50th	75th	90th	95th	
Non-Hispanic whites	2003–2004	8.94 (7.15–11.2)	7.80 (6.30–9.40)	25.9 (19.3–36.6)	115 (61.8–171)	255 (148–522)	1,077
	2005–2006	6.19 (4.18–9.17)	5.90 (3.80–9.20)	15.7 (11.4–21.9)	43.7 (31.2–73.1)	105 (62.2–166)	1,038
	2007–2008	6.24 (5.04–7.74)	5.10 (4.20–6.20)	15.4 (12.2–19.9)	49.8 (37.0–90.2)	142 (103–294)	1,077
	2009–2010	4.10 (3.22–5.21)	3.30 (2.60–4.40)	10.9 (8.10–15.5)	45.5 (29.0–82.7)	124 (79.3–215)	1,206
	2011–2012	2.78 (2.13–3.63)	2.00 (1.60–2.50)	7.40 (5.40–9.70)	34.4 (18.1–67.6)	112 (52.1–178)	813
	2013–2014	1.95 (1.54–2.46)	1.40 (1.10–1.90)	4.70 (3.30–6.50)	19.0 (12.8–25.9)	53.7 (25.2–131)	988
	2015–2016	1.60 (1.33–1.93)	1.30 (1.10–1.60)	4.00 (2.90–5.00)	18.7 (10.4–24.3)	38.0 (28.7–51.9)	781
All Hispanics	2011–2012	7.96 (4.50–14.1)	6.30 (3.20–14.9)	29.1 (16.0–66.7)	196 (84.1–399)	536 (194–1,630)	571
	2013–2014	4.26 (2.84–6.40)	2.80 (1.50–5.00)	11.8 (7.20–22.4)	77.7 (42.7–236)	420 (112–807)	690
	2015–2016	8.79 (4.94–15.6)	6.40 (3.30–14.8)	35.3 (18.7–80.8)	284 (116–503)	633 (415–930)	859
Asians	2011–2012	3.77 (2.17–6.53)	2.40 (1.40–5.40)	13.0 (5.40–43.4)	86.8 (38.6–160)	378 (86.8–810)	352
	2013–2014	2.66 (1.64–4.32)	1.70 (1.20–2.90)	6.20 (3.30–18.5)	50.3 (13.0–154)	154 (38.7–2,450)	289
	2015–2016	2.54 (1.79–3.61)	2.00 (1.40–3.20)	7.60 (4.80–12.5)	30.1 (15.6–55.8)	158 (31.2–318)	275

[a] The LODs for survey years 2003–2004, 2005–2006, 2007–2008, 2009–2010, 2011–2012, 2013–2104, and 2015–2016 are 0.12, 0.2, 0.2, 0.2, 0.2, 0.1, and 0.1 respectively.

CI = confidence interval; LOD = limit of detection

Source: CDC 2019, 2021

Table 5-11. Geometric Mean and Selected Percentiles of Urinary 2,5-Dichlorophenol Concentrations (Creatinine Corrected) (in µg/g of Creatinine) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES) 2003–2016

	Survey years[a]	Geometric mean (95% CI)	Selected percentiles (95% CI)				Sample size
			50th	75th	90th	95th	
Total population	2003–2004	12.5 (10.1–15.6)	9.29 (7.25–12.5)	34.4 (26.8–45.4)	141 (100–251)	578 (313–851)	2,522
	2005–2006	9.31 (6.70–12.9)	7.32 (5.33–10.2)	20.4 (14.8–30.5)	89.3 (54.9–176)	292 (176–640)	2,548
	2007–2008	9.12 (7.35–11.3)	6.24 (5.00–7.77)	24.2 (17.2–30.3)	109 (70.8–175)	409 (234–745)	2,604
	2009–2010	6.36 (5.07–7.99)	4.12 (3.31–5.16)	16.2 (11.7–22.8)	80.2 (59.5–127)	269 (144–505)	2,749
	2011–2012	4.80 (3.65–6.32)	3.19 (2.38–4.43)	11.4 (7.97–17.9)	66.4 (39.9–125)	215 (145–342)	2,487
	2013–2014	2.77 (2.12–3.62)	1.82 (1.43–2.40)	6.80 (4.62–9.72)	32.2 (21.9–45.5)	108 (58.4–270)	2,684
	2015–2016	3.02 (2.25–4.04)	2.03 (1.54–2.74)	8.45 (4.88–14.1)	44.0 (26.2–80.1)	133 (66.8–249)	2,650
Age group							
Age 3-5 years	2015–2016	5.95 (3.51–10.1)	3.51 (1.95–6.90)	17.7 (5.17–45.4)	59.4 (36.4–213)	440 (59.4–1610)	140
Age 6–11 years	2003–2004	15.2 (9.93–23.1)	10.6 (5.87–26.7)	44.7 (28.9–80.0)	183 (95.3–617)	830 (330–2,150)	314
	2005–2006	11.6 (8.90–15.1)	8.00 (5.95–12.6)	24.7 (16.8–37.8)	129 (55.8–242)	419 (151–709)	356
	2007–2008	11.5 (7.95–16.5)	7.70 (5.41–11.7)	29.5 (19.6–50.9)	131 (59.9–239)	420 (170–1,110)	389
	2009–2010	9.36 (5.65–15.5)	6.25 (4.09–9.60)	33.9 (12.6–65.0)	177 (66.1–496)	536 (111–5,950)	415
	2011–2012	5.01 (3.10–8.09)	3.02 (2.00–5.00)	10.6 (5.53–21.7)	98.1 (32.9–166)	377 (125–1,180)	395
	2013–2014	3.66 (2.50–5.36)	2.41 (1.62–3.54)	9.73 (5.25–15.6)	37.6 (16.9–110)	172 (70.4–615)	409
	2015–2016	4.92 (2.92–8.27)	3.07 (1.95–6.19)	15.6 (6.95–38.4)	83.5 (41.2–160)	224 (109–460)	415
Age 12–19 years	2003–2004	12.7 (8.50–18.9)	9.05 (6.17–13.3)	34.8 (18.6–67.0)	177 (67.0–516)	549 (187–2,120)	720
	2005–2006	8.88 (6.34–12.4)	6.91 (4.15–11.1)	23.4 (17.7–30.0)	78.0 (58.5–112)	279 (112–659)	702
	2007–2008	8.79 (6.81–11.4)	5.56 (4.42–7.50)	20.9 (13.8–34.9)	130 (41.8–251)	353 (158–799)	401
	2009–2010	6.44 (4.40–9.42)	4.05 (2.34–8.69)	19.4 (11.6–37.7)	121 (49.3–218)	257 (119–1,180)	420
	2011–2012	4.04 (2.51–6.52)	2.41 (1.54–5.34)	12.1 (5.67–27.6)	47.9 (26.3–99.5)	157 (55.1–324)	388
	2013–2014	2.21 (1.44–3.40)	1.53 (0.915–2.52)	5.16 (2.63–12.0)	22.7 (12.2–38.9)	54.2 (21.7–236)	462
	2015–2016	3.98 (2.62–6.03)	2.61 (1.30–5.15)	13.8 (6.35–26.5)	92.2 (42.0–131)	235 (113–781)	405
Age 20+ years	2003–2004	12.2 (10.1–14.8)	9.13 (7.25–12.4)	32.7 (26.7–42.9)	140 (103–203)	552 (283–838)	1,488
	2005–2006	9.15 (6.43–13.0)	7.29 (5.29–10.0)	19.6 (14.2–30.4)	90.7 (48.5–197)	274 (163–701)	1,490
	2007–2008	8.94 (7.07–11.3)	6.15 (4.93–8.00)	24.3 (16.6–30.6)	101 (70.0–162)	422 (234–729)	1,814
	2009–2010	6.09 (4.97–7.45)	3.97 (3.27–4.78)	14.7 (11.0–20.5)	72.5 (56.6–97.2)	261 (141–446)	1,914
	2011–2012	4.90 (3.67–6.56)	3.33 (2.50–4.51)	11.5 (8.04–18.0)	70.3 (38.8–136)	226 (145–342)	1,704
	2013–2014	2.78 (2.15–3.59)	1.81 (1.44–2.29)	6.67 (4.62–9.47)	32.6 (21.1–51.0)	126 (58.4–325)	1,813

Table 5-11. Geometric Mean and Selected Percentiles of Urinary 2,5-Dichlorophenol Concentrations (Creatinine Corrected) (in µg/g of Creatinine) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES) 2003–2016

	Survey years[a]	Geometric mean (95% CI)	Selected percentiles (95% CI)				Sample size
			50th	75th	90th	95th	
	2015–2016	2.73 (2.04–3.64)	1.89 (1.43–2.55)	6.97 (4.38–11.7)	35.7 (19.3–69.1)	89.9 (50.8–270)	1,690
Gender							
Males	2003–2004	12.2 (9.73–15.3)	9.65 (7.23–12.7)	32.7 (25.3–39.1)	108 (79.0–183)	358 (161–1,080)	1,230
	2005–2006	9.60 (7.17–12.9)	8.11 (5.95–10.5)	20.5 (15.9–28.2)	74.9 (50.5–141)	249 (137–534)	1,270
	2007–2008	9.17 (7.63–11.0)	6.24 (5.22–7.81)	25.5 (19.7–32.4)	110 (70.7–167)	353 (234–572)	1,294
	2009–2010	6.36 (5.04–8.02)	4.21 (3.36–4.97)	16.7 (11.7–24.0)	83.2 (53.7–141)	280 (111–727)	1,399
	2011–2012	4.15 (3.14–5.49)	2.87 (2.14–4.13)	9.73 (6.88–16.1)	52.8 (31.4–106)	157 (125–233)	1,258
	2013–2014	2.49 (1.93–3.22)	1.69 (1.23–2.22)	5.49 (4.18–8.11)	27.4 (19.6–45.8)	88.7 (58.4–160)	1,284
	2015–2016	2.83 (2.12–3.79)	2.01 (1.44–2.73	7.01 (4.81–13.2)	37.0 (22.0–57.8)	121 (55.3–223)	1,307
Females	2003–2004	12.9 (9.91–16.8)	8.95 (6.98–13.2)	37.1 (26.7–56.9)	209 (124–362)	660 (408–940)	1,292
	2005–2006	9.04 (6.18–13.2)	6.60 (4.56–10.4)	20.4 (14.1–33.8)	104 (55.8–199)	309 (149–933)	1,278
	2007–2008	9.07 (6.91–11.9)	6.08 (4.71–8.04)	22.4 (14.7–30.6)	107 (59.2–216)	509 (185–908)	1,310
	2009–2010	6.37 (4.92–8.25)	4.10 (3.09–5.69)	15.6 (11.3–22.1)	77.1 (53.3–148)	267 (151–481)	1,350
	2011–2012	5.53 (4.14–7.37)	3.39 (2.57–5.00)	13.1 (8.84–19.5)	90.1 (45.2–147)	331 (145–557)	1,229
	2013–2014	3.07 (2.30–4.09)	1.96 (1.52–2.54)	8.22 (5.07–11.9)	33.8 (21.7–56.2)	140 (50.4–374)	1,400
	2015–2016	3.2 (2.31–4.44)	2.04 (1.59–2.99)	9.57 (4.74–17.1)	52.8 (27.3–90.7)	149 (71.7–334)	1,343
Race/ethnicity							
Mexican Americans	2003–2004	27.3 (17.4–42.9)	17.8 (9.86–36.3)	79.8 (45.8–138)	809 (196–2,110)	2,200 (1,250–2,480)	616
	2005–2006	29.0 (20.5–41.0)	18.6 (12.9–27.3)	99.4 (61.6–165)	675 (296–1,400)	1,680 (718–2,720)	637
	2007–2008	21.6 (9.44–49.6)	16.4 (5.09–58.9)	83.9 (30.8–281)	572 (182–1,490)	1,490 (700–2,220)	531
	2009–2010	12.9 (5.78–28.8)	9.12 (3.38–26.7)	45.0 (17.3–236)	460 (105–1,000)	1,000 (380–2,800)	566
	2011–2012	6.67 (4.04–11.0)	4.85 (2.25–8.69)	22.4 (12.6–37.6)	189 (49.2–249)	383 (213–981)	316
	2013–2014	4.68 (2.72–8.06)	2.47 (1.36–5.71)	14.5 (7.24–25.0)	91.8 (26.9–559)	559 (89.0–1,330)	438
	2015-2016	9.72 (4.86–19.5)	6.71 (3.08–19.3)	33.1 (13.7–131)	204 (93.1–466)	689 (289–1,240)	513
Non-Hispanic blacks	2003–2004	37.1 (24.3–56.7)	27.4 (17.5–47.7)	103 (63.8–216)	609 (248–1,210)	1,240 (627–2,430)	635
	2005–2006	30.9 (23.6–40.3)	20.5 (17.3–29.1)	104 (57.7–180)	480 (294–1,080)	1,480 (515–3,100)	678
	2007–2008	21.3 (16.2–27.9)	14.6 (10.2–19.7)	64.6 (48.0–101)	529 (217–884)	1,130 (793–1,560)	597
	2009–2010	16.7 (9.19–30.2)	12.5 (6.74–22.0)	58.9 (22.3–106)	349 (92.6–878)	878 (277–3,890)	516
	2011–2012	12.9 (8.32–19.9)	9.41 (6.35–15.1)	34.5 (18.1–75.0)	174 (83.7–567)	744 (236–1,790)	665

Table 5-11. Geometric Mean and Selected Percentiles of Urinary 2,5-Dichlorophenol Concentrations (Creatinine Corrected) (in µg/g of Creatinine) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES) 2003–2016

			Selected percentiles (95% CI)				
	Survey years[a]	Geometric mean (95% CI)	50th	75th	90th	95th	Sample size
	2013–2014	7.07 (3.87–12.9)	5.62 (2.55–10.4)	21.2 (10.0–54.1)	128 (32.7–527)	415 (103–2,580)	609
	2015–2016	14 (8.41–23.3)	9.92 (5.05–18.5)	52.8 (31.5–76.2)	369 (121–1,430)	2,020 (544–4,830)	609
Non-Hispanic whites	2003–2004	9.24 (7.48–11.4)	7.14 (5.67–8.76)	24.8 (18.7–31.7)	79.7 (50.2–141)	216 (124–516)	1,076
	2005–2006	6.52 (4.51–9.43)	5.60 (3.86–8.51)	14.1 (10.7–19.7)	40.2 (28.4–61.6)	110 (47.3–224)	1,038
	2007–2008	6.52 (5.26–8.07)	4.89 (3.95–6.20)	14.4 (11.4–19.2)	53.2 (40.1–75.9)	131 (82.5–249)	1,077
	2009–2010	4.60 (3.59–5.90)	3.27 (2.77–4.10)	10.4 (7.22–15.2)	41.3 (25.0–69.1)	130 (73.4–180)	1,206
	2011–2012	3.40 (2.57–4.49)	2.36 (1.76–3.19)	6.96 (4.70–9.67)	34.5 (16.4–80.1)	126 (55.3–232)	811
	2013–2014	2.03 (1.53–2.69)	1.48 (1.13–1.91)	4.15 (2.96–6.34)	18.2 (10.6–32.5)	45.8 (26.0–86.3)	987
	2015–2016	1.7 (1.45–1.99)	1.33 (1.19–1.60)	3.78 (2.91–4.81)	13.5 (8.89–23.8)	34.4 (23.4–46.3)	781
All Hispanics	2011–2012	8.92 (5.45–14.6)	6.55 (3.50–13.8)	28.8 (16.6–53.6)	184 (97.2–266)	383 (213–1,240)	571
	2013–2014	4.23 (2.77–6.47)	2.50 (1.41–5.07)	11.5 (6.84–18.7)	84.6 (32.2–226)	401 (135–993)	690
	2015–2016	8.96 (4.93–16.3)	6.09 (2.96–16.3)	36.4 (18.9–71.7)	213 (131–354)	597 (271–1,670)	859
Asians	2011–2012	5.05 (2.93–8.69)	2.99 (1.74–7.04)	15.3 (6.51–45.6)	106 (58.7–177)	236 (97.5–632)	352
	2013–2014	3.40 (2.10–5.52)	2.06 (1.33–3.26)	8.99 (3.21–20.8)	45.2 (17.3–158)	207 (32.6–3,020)	288
	2015–2016	3.1 (2.24–4.29)	2.43 (1.56–3.87)	8.75 (5.59–13.7)	31.2 (16.7–111)	127 (39.9–211)	275

[a] The LODs for survey years 2003–2004, 2005–2006, 2007–2008, 2009–2010, 2011–2012, 2013–2104, and 2015–2016 are 0.12, 0.2, 0.2, 0.2, 0.2, 0.1, and 0.1 respectively.

CI = confidence interval; LOD = limit of detection

Source: CDC 2019, 2021

Table 5-12. Geometric Mean and Selected Percentiles of Urinary 2,4,5-Trichlorophenol Concentrations (in µg/L) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES) 1999–2010

			Selected percentiles (95% CI)				
	Survey years[a]	Geometric mean (95% CI)	50th	75th	90th	95th	Sample size
Total population	1999–2000	*	<LOD	1.40 (1.00–3.20)	(5.40 (2.50–16.0)	16.0 (4.3–40.0)	1,994
	2001–2002	*	<LOD	<LOD	<LOD	2.42 (<LOD–8.27)	2,497
	2003–2004	*	<LOD	0.100 (0.100–0.100)	0.200 (0.200–0.300)	0.400 (0.300–0.400)	2,525
	2005–2006	*	<LOD	0.100 (0.100–0.200)	0.300 (0.200–0.300)	0.400 (0.300–0.500)	2,548
	2007–2008	*	<LOD	0.100 (<LOD–0.100)	0.200 (0.200–0.200)	0.300 (0.200–0.300)	2,604
	2009–2010	*	<LOD	<LOD	0.200 (0.200–0.200)	0.300 (0.200–0.300)	2,749
Age group							
Age 6–11 years	1999–2000	*	<LOD	1.4 (1.10–3.40)	4.80 (2.30–11.0)	11/0 (4.20–36.0)	482
	2001–2002	*	<LOD	<LOD	<LOD	2.42 (<LOD–12.7)	570
	2003–2004	*	<LOD	0.100 (0.100–0.200)	0.200 (0.200–0.300)	0.300 (0.200–0.500)	314
	2005–2006	*	<LOD	0.100 (0.100–0.200)	0.300 (0.200–0.400)	0.400 (0.300–0.500)	356
	2007–2008	*	<LOD	0.100 (<LOD–0.100)	0.200 (0.100–0.300)	0.300 (0.200–0.500)	389
	2009–2010	*	<LOD	<LOD	0.200 (0.100–0.200)	0.200 (0.200–0.300)	415
Age 12–19 years	1999–2000	*	<LOD	1.60 (0.940–3.72)	5.40 (2.5–25.0)	24.0 (3.80–41.0)	681
	2001–2002	*	<LOD	<LOD	<LOD	2.19 (<LOD–6.63)	815
	2003–2004	*	<LOD	0.100 (0.100–0.200)	0.200 (0.200–0.300)	0.300 (0.200–0.500)	722
	2005–2006	*	<LOD	0.100 (0.100–0.200)	0.300 (0.200–0.300)	0.400 (0.300–0.500)	702
	2007–2008	*	<LOD	0.100 (<LOD–0.100)	0.200 (0.100–0.200)	0.200 (0.200–0.500)	401
	2009–2010	*	<LOD	0.100 (<LOD–0.100)	0.200 (0.200–0.300)	0.300 (0.200–0.500)	420
Age 20+ years	1999–2000	*	<LOD	1.40 (0.980–3.30)	5.40 (2.40–18.0)	18.0 (4.3–44.0)	831
	2001–2002	*	<LOD	<LOD	<LOD	2.71 (<LOD–8.27)	1,112
	2003–2004	*	<LOD	0.100 (0.100–0.100)	0.300 (0.200–0.300)	0.400 (0.300–0.500)	1,489
	2005–2006	*	<LOD	0.100 (0.100–0.200)	0.300 (0.200–0.300)	0.400 (0.300–0.500)	1,490
	2007–2008	*	<LOD	0.100 (<LOD–0.100)	0.200 (0.200–0.300)	0.300 (0.200–0.400)	1,814
	2009–2010	*	<LOD	<LOD	0.200 (0.200–0.200)	0.300 (0.200–0.300)	1,914

Table 5-12. Geometric Mean and Selected Percentiles of Urinary 2,4,5-Trichlorophenol Concentrations (in µg/L) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES) 1999–2010

			Selected percentiles (95% CI)				
	Survey years[a]	Geometric mean (95% CI)	50th	75th	90th	95th	Sample size
Gender							
Males	1999–2000	*	<LOD	1.40 (0.980–3.80)	5.4 (2.60–8.40)	11.0 (5.30–27.0)	973
	2001–2002	*	<LOD	<LOD	<LOD	5.57 (<LOD–15.8)	1,178
	2003–2004	*	<LOD	0.100 (0.100–0.100)	0.200 (0.200–0.300)	0.400 (0.300–0.400)	1,231
	2005–2006	*	<LOD	0.100 (0.100–0.200)	0.200 (0.200–0.300)	0.400 (0.300–0.500)	1,270
	2007–2008	*	<LOD	0.100 (<LOD–0.100)	0.200 (0.200–0.200)	0.300 (0.200–0.300)	1,294
	2009–2010	*	<LOD	<LOD	0.200 (0.200–0.200)	0.300 (0.200–0.300)	1,399
Females	1999–2000	*	<LOD	1.50 (1.00–3.20)	6.50 (2.30–27.0)	21.0 (3.20–71.0)	1,021
	2001–2002	*	<LOD	<LOD	<LOD	<LOD	1,319
	2003–2004	*	<LOD	0.100 (0.100–0.200)	0.200 (0.200–0.300)	0.400 (0.300–0.400)	1,294
	2005–2006	*	<LOD	0.100 (0.100–0.200)	0.300 (0.200–0.400)	0.500 (0.300–0.500)	1,278
	2007–2008	*	<LOD	0.100 (<LOD–0.100)	0.200 (0.200–0.300)	0.300 (0.200–0.400)	1,310
	2009–2010	*	<LOD	0.100 (<LOD–0.100)	0.200 (0.200–0.200)	0.300 (0.200–0.300)	1,350
Race/ethnicity							
Mexican Americans	1999–2000	*	0.950 (<LOD–1.30)	1.80 (1.30–3.50)	8.60 (4.60–18.0)	21.0 (8.90–33.0)	696
	2001–2002	*	<LOD	<LOD	<LOD	14.9 (<LOD–121)	661
	2003–2004	*	<LOD	0.100 (<LOD–0.200)	0.200 (0.200–0.300)	0.300 (0.200–0.400)	617
	2005–2006	*	<LOD	0.100 (<LOD–0.200)	0.300 (0.200–0.300)	0.400 (0.300–0.500)	637
	2007–2008	*	<LOD	<LOD	0.200 (0.100–0.200)	0.200 (0.200–0.300)	531
	2009–2010	*	<LOD	<LOD	0.100 (<LOD–0.200)	0.200 (0.100–0.300)	566
Non-Hispanic blacks	1999–2000	*	<LOD	1.30 (0.900–2.20)	5.00 (2.00–8.40)	9.00 (3.50–63.0)	521
	2001–2002	*	<LOD	<LOD	<LOD	2.31 (<LOD–9.03)	696
	2003–2004	*	<LOD	0.200 (0.100–0.200)	0.300 (0.200–0.500)	0.400 (0.300–0.700)	636
	2005–2006	*	<LOD	0.200 (0.100–0.200)	0.300 (0.200–0.400)	0.500 (0.300–0.500)	678
	2007–2008	*	<LOD	0.100 (0.100–0.200)	0.200 (0.200–0.300)	0.400 (0.300–0.500)	597
	2009–2010	*	<LOD	0.100 (<LOD–0.100)	0.200 (0.200–0.200)	0.200 (0.200–0.300)	516
Non-Hispanic whites	1999–2000	*	<LOD	1.5 (0.920–3.60)	4.60 (2.40–11.0)	9.20 (4.30–27.0)	603
	2001–2002	*	<LOD	<LOD	<LOD	2.71 (<LOD–8.27)	939
	2003–2004	*	<LOD	0.100 (0.100–0.100)	0.200 (0.200–0.300)	0.400 (0.300–0.400)	1,077
	2005–2006	*	<LOD	0.100 (0.100–0.200)	0.300 (0.200–0.300)	0.400 (0.300–0.600)	1,038
	2007–2008	*	<LOD	0.100 (<LOD–0.100)	0.200 (0.200–0.300)	0.300 (0.200–0.400)	1,077

Table 5-12. Geometric Mean and Selected Percentiles of Urinary 2,4,5-Trichlorophenol Concentrations (in µg/L) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES) 1999–2010

			Selected percentiles (95% CI)				
	Survey years[a]	Geometric mean (95% CI)	50th	75th	90th	95th	Sample size
	2009–2010	*	<LOD	<LOD	0.200 (0.200–0.200)	0.300 (0.200–0.300)	1,206

[a]The LODs for survey years 1999–2000, 2001–2002, 2003–2004, 2005–2006, 2007–2008, and 2009–2010 are 0.9, 0.9, 0.1, 0.1, 0.1, and 0.1, respectively.

* = not calculated; the proportion of results below the LOD was too high to provide a valid result; CI = confidence interval; LOD = limit of detection

Source: CDC 2009, 2019

Table 5-13. Geometric Mean and Selected Percentiles of Urinary 2,4,5-Trichlorophenol Concentrations (Creatinine Corrected) (in µg/g of Creatinine) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES) 1999–2010

			Selected percentiles (95% CI)				
	Survey years[a]	Geometric mean (95% CI)	50th	75th	90th	95th	Sample size
Total population	1999–2000	*	<LOD	2.36 (1.53–3.16)	5.57 (3.24–11.2)	11.9 (5.00–19.6)	1,994
	2001–2002	*	<LOD	<LOD	<LOD	457 (<LOD–7.11)	2,496
	2003–2004	*	<LOD	0.170 (0.160–0.180)	0.280 (0.260–0.310)	0.370 (0.330–0.420)	2,522
	2005–2006	*	<LOD	0.160 (0.150–0.180)	0.290 (0.260–0.320)	0.410 (0.360–0.450)	2,548
	2007–2008	*	<LOD	0.150 (<LOD–0.160)	0.280 (0.230–0.320)	0.390 (0.330–0.470)	2,604
	2009–2010	*	<LOD	<LOD	0.260 (0.240–0.280)	0.350 (0.320–0.390)	2,749

Table 5-13. Geometric Mean and Selected Percentiles of Urinary 2,4,5-Trichlorophenol Concentrations (Creatinine Corrected) (in µg/g of Creatinine) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES) 1999–2010

		Geometric mean	Selected percentiles (95% CI)				Sample
	Survey years[a]	(95% CI)	50th	75th	90th	95th	size
Age group							
Age 6–11 years	1999–2000	*	<LOD	2.29 (1.19–4.78)	5.86 (3.8312.4)	12.8 (5.28–25.4)	482
	2001–2002	*	<LOD	<LOD	<LOD	5.82 (<LOD–32.5)	570
	2003–2004	*	<LOD	0.180 (0.150–0.230)	0.290 (0.250–0.320)	0.370 (0.310–0.540)	314
	2005–2006	*	<LOD	0.180 (0.140–0.200)	0.310 (0.210–0.450)	0.450 (0.320–0.610)	356
	2007–2008	*	<LOD	0.180 (<LOD–0.190)	0.270 (0.210–0.390)	0.430 (0.270–0.580)	389
	2009–2010	*	<LOD	<LOD	0.320 (0.240–0.350)	0.390 (0.320–0.470)	415
Age 12–19 years	1999–2000	*	<LOD	1.44 (0.920–2.50)	3.80 (1.93–11.2)	11.2 (2.62–20.1)	681
	2001–2002	*	<LOD	<LOD	<LOD	2.75 (<LOD–6.74)	814
	2003–2004	*	<LOD	0.120 (0.100–0.140)	0.200 (0.170–0.220)	0.240 (0.220–0.280)	720
	2005–2006	*	<LOD	0.120 (0.110–0.130)	0.210 (0.180–0.240)	0.290 (0.240–0.330)	702
	2007–2008	*	<LOD	0.100 (<LOD–0.120)	0.170 (0.150–0.210)	0.250 (0.170–0.310)	401
	2009–2010	*	<LOD	0.110 (<LOD–0.130)	0.190 (0.150–0.250)	0.280 (0.190–0.380)	420
Age 20+ years	1999–2000	*	<LOD	2.46 (1.60–3.24)	5.75 (3.37–11.5)	11.7 (4.78–19.6)	831
	2001–2002	*	<LOD	<LOD	<LOD	4.57 (<LOD–7.11)	1,112
	2003–2004	*	<LOD	0.180 (0.160–0.180)	0.290 (0.270–0.320)	0.390 (0.350–0.470)	1,488
	2005–2006	*	<LOD	0.170 (0.150–0.190)	0.300 (0.260–0.330)	0.410 (0.370–0.470)	1,490
	2007–2008	*	<LOD	0.150 (<LOD–0.180)	0.290 (0.230–0.350)	0.410 (0.340–0.500)	1,814
	2009–2010	*	<LOD	<LOD	0.270 (0.240–0.280)	0.350 (0.320–0.410)	1,914
Gender							
Males	1999–2000	*	<LOD	1.67 (1.02–3.15)	4.24 (3.05–8.02)	9.55 (4.13–13.6)	973
	2001–2002	*	<LOD	<LOD	<LOD	4.68 (<LOD–8.37)	1,178
	2003–2004	*	<LOD	0.130 (0.110–0.150)	0.230 (0.190–0.260)	0.320 (0.270–0.350)	1,230
	2005–2006	*	<LOD	0.130 (0.120–0.140)	0.220 (0.190–0.240)	0.310 (0.260–0.360)	1,270
	2007–2008	*	<LOD	0.110 (<LOD–0.120)	0.190 (0.180–0.230)	0.300 (0.230–0.340)	1,294
	2009–2010	*	<LOD	<LOD	0.210 (0.190–0.230)	0.280 (0.240–0.330)	1,399
Females	1999–2000	*	<LOD	2.67 (1.79–4.00)	7.95 (3.05–17.8)	16.3 (5.00–29.3)	1,021
	2001–2002	*	<LOD	<LOD	<LOD	<LOD	1,318
	2003–2004	*	<LOD	0.200 (0.180–0.210)	0.320 (0.290–0.350)	0.440 (0.350–0.510)	1,292
	2005–2006	*	<LOD	0.210 (0.180–0.230)	0.350 (0.300–0.410)	0.470 (0.410–0.550)	1,278

Table 5-13. Geometric Mean and Selected Percentiles of Urinary 2,4,5-Trichlorophenol Concentrations (Creatinine Corrected) (in µg/g of Creatinine) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES) 1999–2010

		Geometric mean	Selected percentiles (95% CI)				Sample
	Survey years[a]	(95% CI)	50th	75th	90th	95th	size
	2007–2008	*	<LOD	0.190 (<LOD–0.230)	0.330 (0.280–0.410)	0.470 (0.370–0.580)	1,310
	2009–2010	*	<LOD	0.180 (<LOD–0.190)	0.300 (0.280–0.330)	0.420 (0.330–0.470)	1,350
Race/ethnicity							
Mexican Americans	1999–2000	*	0.980 (<LOD–1.33)	2.49 (1.68–4.24)	6.90 (4.19–12.4)	12.4 (6.88–16.9)	696
	2001–2002	*	<LOD	<LOD	<LOD	12.1 (<LOD–58.0)	661
	2003–2004	*	<LOD	0.140 (<LOD–0.150)	0.240 (0.200–0.280)	0.330 (0.280–0.460)	616
	2005–2006	*	<LOD	0.140 (<LOD–0.160)	0.240 (0.190–0.320)	0.350 (0.290–0.380)	637
	2007–2008	*	<LOD	<LOD	0.210 (0.180–0.250)	0.270 (0.240–0.320)	531
	2009–2010	*	<LOD	<LOD	0.190 (<LOD–0.230)	0.290 (0.220–0.330)	566
Non-Hispanic blacks	1999–2000	*	<LOD	1.16 (0.820–2.31)	3.43 (2.20–6.32)	7.96 (2.69–18.2)	521
	2001–2002	*	<LOD	<LOD	<LOD	2.81 (<LOD–9.17)	695
	2003–2004	*	<LOD	0.120 (0.100–0.150)	0.230 (0.170–0.290)	0.310 (0.230–0.390)	635
	2005–2006	*	<LOD	0.110 (0.100–0.140)	0.210 (0.170–0.260)	0.320 (0.260–0.360)	678
	2007–2008	*	<LOD	0.120 (0.100–0.140)	0.200 (0.170–0.250)	0.290 (0.230–0.420)	597
	2009–2010	*	<LOD	0.090 (<LOD–0.110)	0.160 (0.130–0.200)	0.220 (0.160–0.380)	516
Non-Hispanic whites	1999–2000	*	<LOD	2.44 (1.53–3.24)	4.78 (3.47–8.43	9.64 (4.27–17.8)	603
	2001–2002	*	<LOD	<LOD	<LOD	4.73 (<LOD–8.37)	939
	2003–2004	*	<LOD	0.180 (0.160–0.190)	0.290 (0.260–0.320)	0.370 (0.340–0.440)	1,076
	2005–2006	*	<LOD	0.180 (0.160–0.190)	0.300 (0.270–0.350)	0.410 (0.360–0.500)	1,038
	2007–2008	*	<LOD	0.160 (<LOD–0.190)	0.300 (0.250–0.360)	0.440 (0.330–0.510)	1,077
	2009–2010	*	<LOD	<LOD	0.280 (0.250–0.320)	0.370 (0.330–0.410)	1,206

[a] The LODs for survey years 1999–2000, 2001–2002, 2003–2004, 2005–2006, 2007–2008, and 2009–2010 are 0.9, 0.9, 0.1, 0.1, 0.1, and 0.1, respectively.

* = not calculated; the proportion of results below the LOD was too high to provide a valid result; CI = confidence interval; LOD = limit of detection

Source: CDC 2009, 2019

Table 5-14. Geometric Mean and Selected Percentiles of Urinary 2,4,6-Trichlorophenol Concentrations (in µg/L) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES) 1999–2010

			Selected percentiles (95% CI)				
	Survey years[a]	Geometric mean (95% CI)	50th	75th	90th	95th	Sample size
Total population	1999–2000	2.85 (2.55–3.18)	2.50 (2.40–2.70)	4.9 (3.80–7.70)	15.0 (7.80–25.0)	25.0 (15.0–44.0)	1,989
	2001–2002	*	1.68 (<LOD–2.44)	5.95 (4.89–6.63)	10.8 (9.98–11.7)	14.9 (13.4–17.9)	2,502
	2003–2004	*	<LOD	0.500 (<LOD–0.600)	1.00 (0.800–1.20)	1.40 (1.20–1.80)	2,525
	2005–2006	*	<LOD	0.600 (<LOD–0.700)	1.00 (0.800–1.20)	1.40 (1.20–1.80)	2,548
	2007–2008	*	<LOD	<LOD	0.800 (0.700–0.900)	1.20 (1.00–1.30)	2,604
	2009–2010	*	<LOD	0.500 (<LOD–0.600)	0.800 (0.700–0.900)	1.10 (1.00–1.40)	2,749
Age group							
Age 6–11 years	1999–2000	4.47 (3.36–5.95)	3.80 (2.70–6.40)	11.0 (4.80–20.0)	24.0 (14.0–38.0)	33.0 (20.5–46.0)	481
	2001–2002	3.08 (2.52–3.76)	3.00 (1.91–4.32)	7.79 (5.73–9.99)	13.4 (10.6–17.3)	19.2 (14.1–25.3)	574
	2003–2004	*	<LOD	0.600 (0.500–0.700)	1.10 (0.800–1.40)	1.90 (1.10–3.10)	314
	2005–2006	*	<LOD	0.700 (0.600–0.900)	1.30 (1.00–2.30)	2.70 (1.30–5.40)	356
	2007–2008	*	<LOD	0.600 (<LOD–0.700)	1.10 (0.900–1.40)	1.60 (1.30–2.10)	389
	2009–2010	*	<LOD	0.500 (<LOD–0.600)	0.900 (0.700–1.20)	1.30 (0.900–2.20)	415
Age 12–19 years	1999–2000	3.56 (3.0–4.23)	3.00 (2.60–3.70)	6.00 (4.30–11.0)	20.4 (9.60–37.0)	37.0 (20.0–54.0)	678
	2001–2002	3.24 (2.74–3.84)	3.26 (2.33–4.40)	7.49 (6.45–9.40)	13.6 (11.0–18.2)	19.4 (17.3–26.6)	820
	2003–2004	*	<LOD	0.600 (0.500–0.800)	1.20 (0.900–1.70)	1.80 (1.50–2.10)	722
	2005–2006	*	<LOD	0.600 (<LOD–0.800)	1.00 (0.800–1.30)	1.30 (1.20–1.70)	702
	2007–2008	*	<LOD	0.600 (<LOD–0.700)	0.800 (0.700–1.10)	1.10 (0.800–1.70)	401
	2009–2010	*	<LOD	0.600 (<LOD–0.700)	0.900 (0.700–1.30)	1.30 (0.900–1.90)	420
Age 20+ years	1999–2000	2.52 (2.23–2.85)	2.40 (2.10–2.45)	4.20 (3.50–5.30)	12.0 (6.00–21.0)	21.0 (11.0–41.0)	830
	2001–2002	*	<LOD	4.89 (3.70–6.28)	9.66 (8.72–10.7)	13.3 (11.8–15.2)	1,109
	2003–2004	*	<LOD	0.500 (<LOD–0.600)	1.00 (0.800–1.10)	1.30 (1.10–1.70)	1,489
	2005–2006	*	<LOD	0.600 (<LOD–0.700)	1.00 (0.800–1.20)	1.30 (1.20–1.80)	1,490
	2007–2008	*	<LOD	<LOD	0.800 (0.700–0.900)	1.10 (0.900–1.30)	1,814
	2009–2010	*	<LOD	<LOD	0.800 (0.700–0.900)	1.10 (1.00–1.20)	1,914
Gender							
Males	1999–2000	2.92 (2.58–3.31)	2.60 (2.40–2.90)	5.20 (3.90–8.10)	15.0 (8.48–26.0)	26.0 (15.0–38.0)	970
	2001–2002	*	2.36 (1.70–3.04)	6.65 (5.98–7.53)	12.1 (10.8–13.1)	17.0 (13.6–22.2)	1,178
	2003–2004	*	<LOD	0.600 (<LOD–0.600)	1.00 (0.800–1.10)	1.30 (1.10–1.80)	1,231
	2005–2006	*	<LOD	0.600 (<LOD–0.800)	1.10 (0.900–1.30)	1.60 (1.20–2.00)	1,270
	2007–2008	*	<LOD	0.500 (<LOD–0.600)	0.900 (0.700–1.00)	1.20 (1.10–1.40)	1,294

Table 5-14. Geometric Mean and Selected Percentiles of Urinary 2,4,6-Trichlorophenol Concentrations (in µg/L) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES) 1999–2010

		Geometric mean	Selected percentiles (95% CI)				Sample
	Survey years[a]	(95% CI)	50th	75th	90th	95th	size
	2009–2010	*	<LOD	<LOD	0.800 (0.700–0.900)	1.10 (1.00–1.20)	1,399
Females	1999–2000	2.78 (2.35–3.28)	2.40 (2.30–2.60)	4.80 (3.40–7.59)	16.0 (6.40–32.0)	25.0 (14.0–50.0)	1,019
	2001–2002	*	<LOD	4.69 (3.59–6.09)	9.75 (8.25–11.6)	13.3 (11.7–16.6)	1,325
	2003–2004	*	<LOD	0.500 (<LOD–0.600)	1.10 (0.900–1.20)	1.40 (1.10–2.00)	1,294
	2005–2006	*	<LOD	0.500 (<LOD–0.600)	0.900 (0.800–1.20)	1.30 (1.10–1.70)	1,278
	2007–2008	*	<LOD	<LOD	0.800 (0.700–0.900)	1.10 (0.900–1.40)	1,310
	2009–2010	*	<LOD	0.500 (<LOD–0.600)	0.800 (0.700–1.00)	1.10 (0.900–1.60)	1,350
Race/ethnicity							
Mexican Americans	1999–2000	2.70 (2.20–3.32)	2.70 (2.10–3.10)	4.90 (4.20–6.70)	15.0 (8.20–23.0)	23.0 (14.0–43.0)	694
	2001–2002	*	2.07 (<LOD–3.23)	5.31 (3.95–6.54)	11.4 (8.51–12.8)	15.6 (12.6–19.8)	677
	2003–2004	*	<LOD	0.700 (0.600–0.800)	1.20 (1.10–1.60)	1.80 (1.30–2.00)	617
	2005–2006	*	<LOD	0.600 (0.500–0.700)	1.00 (0.800–1.20)	1.30 (1.20–1.70)	637
	2007–2008	*	<LOD	<LOD	0.700 (0.700–0.900)	1.00 (0.900–1.20)	531
	2009–2010	*	<LOD	0.500 (<LOD–0.600)	0.900 (0.700–1.10)	1.10 (0.900–1.30)	566
Non-Hispanic blacks	1999–2000	3.14 (2.40–4.12)	2.80 (2.10–3.40)	6.60 (3.40–14.0)	18.0 (9.30–33.0)	32.0 (16.0–68.0)	519
	2001–2002	2.78 (2.18–3.53)	2.58 (1.32–4.02)	6.45 (5.09–7.67)	11.1 (8.87–14.9)	17.9 (11.8–24.7)	696
	2003–2004	*	<LOD	0.900 (0.700–1.00)	1.40 (1.10–1.90)	2.00 (1.50–2.70)	636
	2005–2006	*	<LOD	0.800 (0.700–1.10)	1.50 (1.20–1.90)	2.20 (1.60–3.30)	678
	2007–2008	*	<LOD	0.600 (0.500–0.600)	1.00 (0.900–1.10)	1.30 (1.10–1.60)	597
	2009–2010	*	<LOD	0.700 (0.600–0.800)	1.10 (0.900–1.30)	1.50 (1.20–2.00)	516
Non-Hispanic whites	1999–2000	2.74 (2.46–3.06)	2.45 (2.30–2.80)	4.60 (3.80–6.60)	13.0 (6.60–21.0)	21.0 (12.0–37.0)	602
	2001–2002	*	1.57 (<LOD–2.20)	6.10 (5.01–6.65)	10.7 (9.67–12.3)	14.7 (13.3–17.9)	931
	2003–2004	*	<LOD	<LOD	0.800 (0.700–1.00)	1.20 (1.00–1.50)	1,077
	2005–2006	*	<LOD	0.500 (<LOD–0.700)	0.900 (0.700–1.30)	1.30 (1.10–1.80)	1,038
	2007–2008	*	<LOD	<LOD	0.800 (0.700–0.900)	1.20 (1.00–1.40)	1,077
	2009–2010	*	<LOD	<LOD	0.700 (0.600–0.900)	1.00 (0.800–1.30)	1,206

[a] The LODs for survey years 1999–2000, 2001–2002, 2003–2004, 2005–2006, 2007–2008, and 2009–2010 are 1.0, 1.3, 0.5, 0.5, 0.5, and 0.5, respectively.

* = not calculated; the proportion of results below the LOD was too high to provide a valid result; CI = confidence interval; LOD = limit of detection

Source: CDC 2009, 2019

Table 5-15. Geometric Mean and Selected Percentiles of Urinary 2,4,6-Trichlorophenol Concentrations (Creatinine Corrected) (in µg/g of Creatinine) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES) 1999–2010

		Geometric mean	Selected percentiles (95% CI)				Sample
	Survey years[a]	(95% CI)	50th	75th	90th	95th	size
Total population	1999–2000	2.54 (2.30–2.81)	2.38 (2.14–2.68)	4.91 (3.83–6.49)	12.1 (8.67–17.0)	21.2 (13.6–31.5)	1,989
	2001–2002	*	2.43 (<LOD–2.75)	4.38 (4.184.78)	8.33 (7.10–9.26)	11.6 (9.25–15.6)	2,502
	2003–2004	*	<LOD	0.710 (<LOD–0.780)	1.25 (1.17–1.35)	1.75 (1.59–2.06)	2,522
	2005–2006	*	<LOD	0.720 (<LOD–0.760)	1.27 (1.17–1.38)	1.75 (1.59–1.94)	2,548
	2007–2008	*	<LOD	<LOD	1.25 (1.06–1.42)	1.75 (1.52–2.19)	2,604
	2009–2010	*	<LOD	0.710 (<LOD–0.760)	1.21 (1.13–1.35)	1.67 (1.55–1.84)	2,749
Age group							
Age 6–11 years	1999–2000	4.82 (3.87–6.00)	4.71 (3.41–6.53)	11.5 (7.63–15.3)	22.7 (14.1–32.6)	32.6 (22.7–36.8)	481
	2001–2002	4.00 (3.28–4.87)	4.01 (3.29–4.81)	8.26 (6.16–10.4)	13.9 (9.51–21.5)	21.2 (12.9–64.1)	574
	2003–2004	*	<LOD	0.920 (0.850–1.13)	1.59 (1.22–1.91)	2.11 (1.46–4.55)	314
	2005–2006	*	<LOD	0.880 (0.740–1.06)	1.59 (1.21–2.06)	2.50 (1.61–5.20)	356
	2007–2008	*	<LOD	0.900 (<LOD–0.930)	1.46 (1.14–1.67)	2.33 (1.52–2.92)	389
	2009–2010	*	<LOD	0.850 (<LOD–1.03)	1.59 (1.17–1.74)	1.85 (1.67–2.33)	415
Age 12–19 years	1999–2000	2.40 (2.08–2.78)	2.33 (1.95–2.68)	4.35 (3.13–6.00)	11.6 (6.94–13.6)	14.4 (11.3–23.6)	678
	2001–2002	2.51 (2.18–2.90)	2.78 (2.09–3.17)	4.52 (3.83–5.92)	8.29 (6.81–9.89)	12.5 (8.73–22.8)	819
	2003–2004	*	<LOD	0.580 (0.510–0.660)	0.970 (0.830–1.10)	1.21 (1.09–1.49)	720
	2005–2006	*	<LOD	0.550 (<LOD–0.630)	0.970 (0.690–1.17)	1.40 (1.08–1.59)	702
	2007–2008	*	<LOD	0.550 (<LOD–0.610)	0.830 (0.730–1.03)	1.30 (0.930–1.48)	401
	2009–2010	*	<LOD	0.590 (<LOD–0.700)	0.970 (0.690–1.23)	1.23 (0.920–1.66)	420
Age 20+ years	1999–2000	2.32 (2.04–2.63)	2.22 (1.89–2.56)	4.25 (3.38–5.63)	10.0 (6.72–16.9)	19.6 (10.9–34.4)	830
	2001–2002	*	<LOD	4.05 (3.66–4.38)	7.10 (6.43–7.72)	9.82 (8.53–11.9)	1,109
	2003–2004	*	<LOD	0.710 (<LOD–0.770)	1.25 (1.17–1.35)	1.75 (1.59–2.00)	1,488
	2005–2006	*	<LOD	0.730 (<LOD–0.780)	1.30 (1.17–1.40)	1.75 (1.57–2.06)	1,490
	2007–2008	*	<LOD	<LOD	1.30 (1.06–1.46)	1.84 (1.52–2.33)	1,814
	2009–2010	*	<LOD	<LOD	1.21 (1.13–1.35)	1.67 (1.52–1.94)	1,914

Table 5-15. Geometric Mean and Selected Percentiles of Urinary 2,4,6-Trichlorophenol Concentrations (Creatinine Corrected) (in µg/g of Creatinine) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES) 1999–2010

		Geometric mean	Selected percentiles (95% CI)				Sample
	Survey years[a]	(95% CI)	50th	75th	90th	95th	size
Gender							
Males	1999–2000	2.24 (1.99–2.53)	2.15 (1.82–2.42)	4.41 (3.56–5.88)	10.8 (7.04–16.4)	18.0 (11.5–28.5)	970
	2001–2002	*	2.23 (1.91–2.65)	4.22 (3.77–4.73)	8.04 (6.70–9.17)	12.2 (8.79–17.7)	1,178
	2003–2004	*	<LOD	0.560 (<LOD–0.600)	0.920 (0.820–1.10)	1.30 (1.17–1.46)	1,230
	2005–2006	*	<LOD	0.600 (<LOD–0.650)	1.00 (0.850–1.13)	1.43 (1.25–1.59)	1,270
	2007–2008	*	<LOD	0.530 (<LOD–0.600)	0.930 (0.830–1.06)	1.46 (1.18–1.59)	1,294
	2009–2010	*	<LOD	<LOD	0.980 (0.850–1.12)	1.33 (1.13–1.59)	1,399
Females	1999–2000	2.88 (2.49–3.33)	2.63 (2.25–2.96)	5.53 (3.88 –7.23)	13.3 (9.65–21.9)	25.1 (13.3–37.0)	1,019
	2001–2002	*	<LOD	4.58 (4.19–5.11)	8.40 (7.27–9.51)	10.9 (9.26–13.6)	1,324
	2003–2004	*	<LOD	0.900 (<LOD–0.960)	1.59 (1.35–1.75)	2.19 (1.75–2.63)	1,292
	2005–2006	*	<LOD	0.850 (<LOD–0.970)	1.46 (1.30–1.67)	2.06 (1.67–2.50)	1,278
	2007–2008	*	<LOD	<LOD	1.46 (1.23–1.75)	2.19 (1.67–2.50)	1,310
	2009–2010	*	<LOD	0.850 (<LOD–0.920)	1.46 (1.30–1.59)	2.06 (1.62–2.33)	1,350
Race/ethnicity							
Mexican Americans	1999–2000	2.43 (2.06–2.87)	2.50 (2.22–2.82)	5.44 (3.87–7.10)	10.8 (8.46–14.9)	18.4 (12.1–21.8)	694
	2001–2002	*	2.22 (<LOD–2.88)	4.25 (3.47–5.76)	8.15 (6.21–11.1)	11.6 (9.63–13.9)	677
	2003–2004	*	<LOD	0.760 (0.600–0.900)	1.15 (0.970–1.38)	1.59 (1.18–2.42)	616
	2005–2006	*	<LOD	0.650 (0.570–0.700)	1.03 (0.860–1.19)	1.46 (1.11–1.94)	637
	2007–2008	*	<LOD	<LOD	1.05 (0.910–1.17)	1.35 (1.13–1.57)	531
	2009–2010	*	<LOD	0.690 (<LOD–0.760)	1.00 (0.900–1.33)	1.67 (1.13–2.18)	566
Non-Hispanic blacks	1999–2000	2.13 (1.65–2.76)	1.90 (1.60–2.52)	4.00 (2.76–8.02)	11.6 (5.32–19.7)	19.5 (10.9–29.5)	519
	2001–2002	1.98 (1.55–2.52)	2.02 (1.48–2.76)	3.83 (3.17–4.88)	6.52 (5.50–8.06)	9.91 (7.14–13.2)	695
	2003–2004	*	<LOD	0.600 (0.560–0.640)	0.950 (0.800–1.10)	1.34 (1.06–1.67)	635
	2005–2006	*	<LOD	0.630 (0.540–0.740)	1.03 (0.830–1.49)	1.59 (1.13–2.07)	678
	2007–2008	*	<LOD	0.520 (0.470–0.620)	1.00 (0.830–1.13)	1.40 (1.13–1.52)	597
	2009–2010	*	<LOD	0.560 (0.490–0.610)	0.830 (0.750–0.950)	1.17 (0.920–1.52)	516

Table 5-15. Geometric Mean and Selected Percentiles of Urinary 2,4,6-Trichlorophenol Concentrations (Creatinine Corrected) (in µg/g of Creatinine) for the U.S. Population from the National Health and Nutrition Examination Survey (NHANES) 1999–2010

			Selected percentiles (95% CI)				
	Survey years[a]	Geometric mean (95% CI)	50th	75th	90th	95th	Sample size
Non-Hispanic whites	1999–2000	2.59 (2.33–2.88)	2.42 (2.20–2.77)	4.87 (3.83–6.06)	11.2 (7.62–15.5)	19.6 (12.9–32.8)	602
	2001–2002	*	2.63 (<LOD–2.88)	4.60 (4.29–4.98)	8.56 (7.22–9.65)	12.0 (9.25–17.1)	931
	2003–2004	*	<LOD	<LOD	1.30 (1.17–1.46)	1.75 (1.59–2.11)	1,076
	2005–2006	*	<LOD	0.760 (<LOD–0.830)	1.35 (1.25–1.50)	1.79 (1.60–2.06)	1,038
	2007–2008	*	<LOD	<LOD	1.35 (1.13–1.52)	1.84 (1.52–2.50)	1,077
	2009–2010	*	<LOD	<LOD	1.30 (1.18–1.46)	1.73 (1.59–2.06)	1,206

[a] The LODs for survey years 1999–2000, 2001–2002, 2003–2004, 2005–2006, 2007–2008, and 2009–2010 are 1.0, 1.3, 0.5, 0.5, 0.5, and 0.5, respectively.

* = not calculated; the proportion of results below the LOD was too high to provide a valid result; CI = confidence interval; LOD = limit of detection

Source: CDC 2009, 2019

chlorobenzene, but they did not have an explanation for the higher tetrachlorophenol concentrations (Angerer et al. 1992).

An industrial hygiene investigation of workers exposed to chlorophenols at a sawmill indicated that dermal exposure was the most important route (Lindroos et al. 1987). The workers were exposed to a wood preservative that contained 80% 2,3,4,6-TeCP, 10–20% 2,4,6-TCP, and 5% pentachlorophenol.

Median urinary concentrations of total chlorophenols were 7.8 µmol/L in workers with the skin as the main route of exposure, 1.4 µmol/L in workers with combined inhalation and skin exposure, and 0.9 µmol/L in workers with inhalation as the principal route of exposure.

Urinary chlorophenol levels were analyzed in the fifth German Environmental Survey on Children and Adolescents 2014–2017 (GerES V) study that collected urine samples of 485 3–17-year-old children and adolescents (Schmied-Tobies et al. 2021). The results of this study are summarized in Table 5-16.

Table 5-16. Urinary Concentrations (µg/L)from 485 Subjects in the GerES V Study

Compound	N<LOQ	% ≥LOQ	10th	50th	90th	95th	98th	Max	AM	GM
2-CP	14	97	0.1	0.2	0.6	0.9	1.8	5.2	0.35	0.26
4-CP	0	100	0.6	1.4	3.2	4.5	6.2	29.3	1.8	1.38
2,4-DCP	12	98	0.1	0.2	0.5	0.8	1.3	15.2	0.37	0.24
2,5-DCP	23	95	0.1	0.2	0.8	1.6	4.6	357	2.05	0.26
2,6-DCP	362	25	<LOQ	<LOQ	0.1	0.1	0.3	0.7	<LOQ	<LOQ
2,3,4-TCP	402	17	<LOQ	<LOQ	0.1	0.1	0.2	0.5	<LOQ	<LOQ
2,4,5-TCP	370	24	<LOQ	<LOQ	0.1	0.2	0.3	0.9	<LOQ	<LOQ
2,4,6-TCP	134	72	<LOQ	0.1	0.4	0.6	1.4	2.8	0.2	0.13
2,3,4,6-TeCP	270	44	<LOQ	<LOQ	0.3	0.3	0.4	2.2	0.13	<LOQ

AM = arithmetic mean; CP = chlorophenol; DCP = dichlorophenol; GerES V = Fifth German Environmental Survey on Children and Adolescents; GM = geometric mean; LOQ = limit of quantitation; Max = maximum; TCP = trichlorophenol; TeCP = tetrachlorophenols

Source: Schmied-Tobies et al. 2021; under the terms of the Creative Commons Attribution-Non-Commercial-No Derivatives License (CC BY NC ND; https://creativecommons.org/licenses/by-nc-nd/4.0/)

As with the general population, occupational exposure to chlorophenols can also occur following accidents that result in the release of these chemicals to the environment, such as the previously discussed train derailment. On the day of the accident, 2-CP air concentrations of 0.02–0.7 mg/m^3 (0.004–0.19 ppm) were detected in the immediate vicinity (EPA 1982). Eighteen days after the spill, air concentrations were reduced to <2 μg/m^3 (<0.5 ppb). Urine levels in the clean-up workers were 1.98 mg/L approximately 2 months following the spill; however, the pathways, duration, and time of exposure were not recorded, so that the exposure levels cannot be estimated (EPA 1982).

Potential exposure to chlorophenols tends to be limited because of the pronounced odor and taste imparted by the presence of these substances. While taste and odor thresholds do vary across the population, low concentrations of chlorophenols can be detected by most people. For example, the odor of 2,4-DCP can be detected in water at 0.35 μg/L (Hoak 1957), and 2,4-DCP can be tasted in water at 8 pg/L (Burttschell et al. 1959). Odor thresholds as low as 0.3–9.15 μg/L in water have also been reported for chlorophenols (Hoak 1957). Although chlorophenols have low odor thresholds in water, 2-CP, 4-CP, 2,4-DCP, and 2,4,6-TCP have been noted to affect the flavor of fish at concentrations of about 2–43 times lower than the odor thresholds for these compounds in water (Persson 1984). Data for the other chlorophenols discussed in this profile were not available.

Ye et al. (2006) reported that 2,4-DCP, 2,4,5-TCP and 2,4,6-TCP were each detected in 5% of 20 pooled breast milk samples (detection limits 0.10–1.22 ng/mL) obtained from a group of females who had no known occupational exposure to these compounds. 2,5-DCP was tested for, but not identified in any samples. The 95th percentile concentration of 2,5-DCP in amniotic fluid from 97 pregnant females referred for amniocentesis screening at the Mount Sinai Medical Center in New York, New York was 5.2 μg/L (Philippat et al. 2013). 2,4-DCP levels were below the detection limits in each case; however, only 11 amniotic fluid samples were tested for 2,4-DCP.

5.7 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

In comparison to members of the general population, workers in certain occupational groups have much greater potential for exposure to high concentrations of chlorophenols (EPA 1982). While quantitative data are not available, workers involved in the production of either chlorophenols or chemicals synthesized from chlorophenols are potentially the most heavily exposed (WHO 1989). Exposure may occur through both inhalation and dermal absorption. Workers in plants that use chlorobenzene are also likely to be heavily exposed to monochlorophenols via the metabolism of inhaled chlorobenzene to monochlorophenols (Kusters and Lauwerys 1990; Ogata et al. 1991; Yoshida et al. 1986). However, most of the inhaled chlorobenzene was metabolized to 4-chlorocatechol rather than chlorophenols, as the average exposed worker excreted 3 times more 4-chlorocatechol than chlorophenols in the urine (Kusters and Lauwerys 1990; Yoshida et al. 1986); thus, exposure via metabolism of chlorobenzene is not an important route of exposure.

Workers at sawmills where the higher chlorinated phenols are used as wood preservatives have the highest potential for being exposed to tetrachlorophenols (WHO 1989). The observation of higher urinary concentrations of tetrachlorophenols during hot humid weather when use of protective clothing was minimal (geometric means of 196.7 ppm in hot humid weather and 98.5 ppm in cooler weather) suggests that dermal contact is an important route of exposure to tetrachlorophenols in these workers (Kleinman et al. 1986). The higher volatility of tetrachlorophenols in warmer weather may have also contributed to the higher urinary concentrations of tetrachlorophenols found when the weather was hot. Higher general population exposure may occur through dermal or oral contact with contaminated soils and/or groundwater in the vicinity of disposal or accident sites and through dermal or oral contact with surface waters into which chlorinated effluents have been discharged (EPA 1982). In addition, inhalation and metabolism of chlorobenzene found in urban air can result in higher exposure to monochlorophenols (Angerer et al. 1992, 1993).