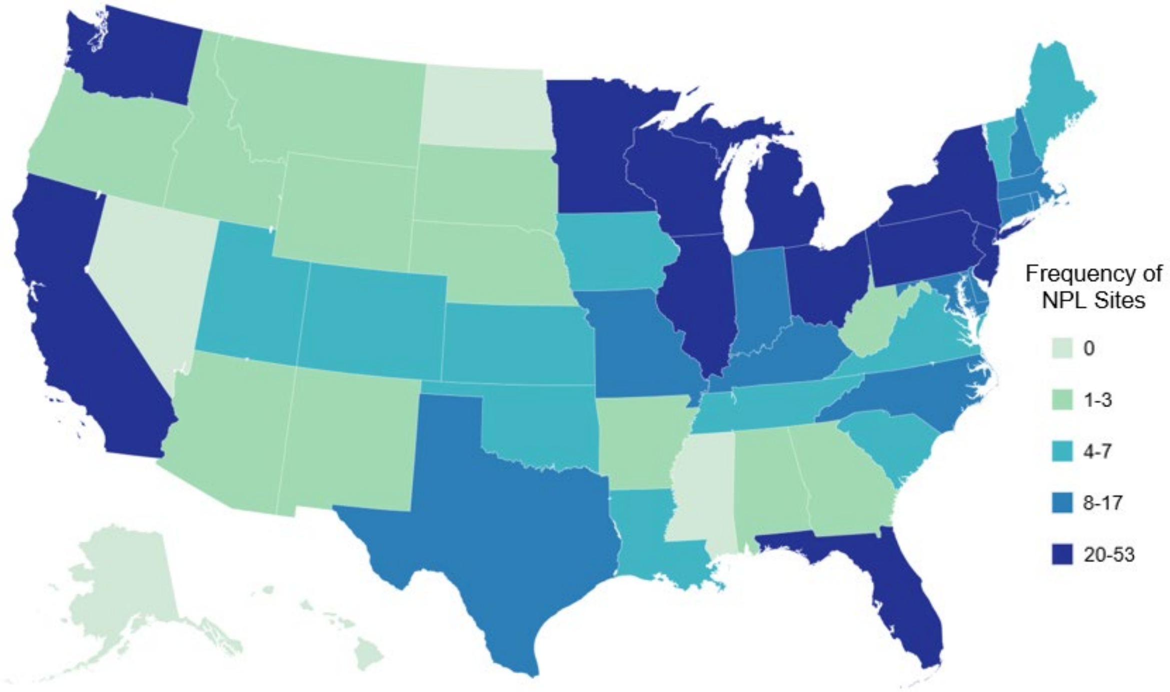
CHAPTER 5. POTENTIAL FOR HUMAN EXPOSURE

5.1 OVERVIEW

Vinyl chloride has been identified in at least 594 of the 1,868 hazardous waste sites that have been proposed for inclusion on the EPA National Priorities List (NPL) (ATSDR 2022). However, the number of sites in which vinyl chloride has been evaluated is not known. The number of sites in each state is shown in Figure 5-1. Of these sites, 590 are located within the United States, 1 site is located in the Virgin Islands, and 3 sites are located in Puerto Rico (not shown).

Figure 5-1. Number of NPL Sites with Vinyl Chloride Contamination



Source: ATSDR 2022

- The major route of exposure to vinyl chloride is through inhalation. This mostly occurs in the occupational setting but can occur near manufacturing facilities, hazardous waste sites, and natural gas extraction sites, where the air may be contaminated.

- Inhalation of cigarette and cigar smoke can also be an exposure route.

- In air, vinyl chloride will degrade photochemically with a half-life of 1–2 days.

- Vinyl chloride released to water is mostly expected to volatilize into the atmosphere. Small amounts could degrade by photochemical reaction and biodegradation.

- Vinyl chloride released to the soil is expected to volatilize or leach into groundwater.
- Aerobically, vinyl chloride is expected to degrade by 25% in a week and by >99% in 15.4 weeks. The rate of anaerobic degradation is dependent on the components of the media (e.g., increased iron).

Most vinyl chloride entering the environment is discharged to the air where it is degraded by reaction with photochemically generated atmospheric oxidants with a typical half-life of a few days. The bacterial degradation of chlorinated solvents such as trichloroethylene, tetrachloroethylene, 1,1,1-trichloroethane, and cis-dichloroethene can also produce vinyl chloride as a degradation product. Most emissions of vinyl chloride arise from its use in the production of PVC materials and copolymers. Over the past several decades, significant reductions in vinyl chloride emissions have been achieved from improved engineering controls in PVC manufacturing facilities. Moreover, optimization of the PVC production process has lowered residual levels of vinyl chloride in finished products such as PVC pipe and food and nonfood packaging material.

If released to water, vinyl chloride is expected to volatilize rapidly. Degradation processes such as hydrolysis and biodegradation occur slowly in comparison to the rate of volatilization. Vinyl chloride is not expected to bioconcentrate in aquatic organisms. When released to soil, volatilization is the most important environmental fate process, although it possesses high mobility in soil.

General population exposure to vinyl chloride is typically low; however, some populations that are exposed from an accidental release such as the Norfolk Southern train derailment that occurred on February 3, 2023, near East Palestine, Ohio are at risk for higher exposures. Occupational exposure to vinyl chloride is higher than exposures to the general population; however, since the mid-1970s regulatory changes and voluntary improvements in the PVC manufacturing process have dramatically lowered workplace exposure.

5.2 PRODUCTION, IMPORT/EXPORT, USE, AND DISPOSAL

5.2.1 Production

Table 5-1 summarizes information on companies that reported the production, import, or use of vinyl chloride for the Toxics Release Inventory (TRI) in 2021 (TRI21 2023a). TRI data should be used with caution since only certain types of industrial facilities are required to report. This is not an exhaustive list.

Vinyl chloride was first produced commercially in the 1930s by reacting hydrogen chloride with acetylene. Currently, vinyl chloride is produced commercially by the chlorination of ethylene through one of two processes, direct chlorination or oxychlorination. Direct chlorination reacts ethylene with chlorine to produce 1,2-dichloroethane. Similarly, oxychlorination produces 1,2-dichloroethane, but this is accomplished by reacting ethylene with dry hydrogen chloride and oxygen.

After both processes, the 1,2-dichloroethane is subjected to high pressures (2.5–3.0 megapascals) and temperatures (500–550°C). This causes the 1,2-dichloroethane to undergo pyrolysis, or thermal cracking, which forms the vinyl chloride monomer and hydrogen chloride. The vinyl chloride monomer is then isolated (Cowfer and Magistro 1985). The technical-grade product is available in 99.9% purity (NLM 2023). Efforts have been made to minimize by-product formation (hydrocarbons, chlorinated hydrocarbons, and unreacted material) in 1,2-dichloroethane pyrolysis (Cowfer and Magistro 1985).

Table 5-1 summarizes the facilities in the United States that either manufacture or process vinyl chloride. The Toxic Release Inventory (TRI21 2023a) provides the data for Table 5-1 including the maximum amounts of vinyl chloride that are present at these sites and the end uses of vinyl chloride. Table 5-2 lists the 12 reporting facilities that solely manufacture vinyl chloride for commercial purposes and their production capacities (EPA 2021). Because of confidential business information, specific quantities are not available (EPA 2021).

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

State[a]	Number of facilities	Minimum amount on site in pounds[b]	Maximum amount on site in pounds[b]	Activities and uses[c]
AL	1	100,000	999,999	6
AR	1	1,000	9,999	1, 2, 3, 5, 9, 12
IL	1	1,000,000	9,999,999	6
KY	3	1,000,000	9,999,999	1, 4, 6
LA	8	10,000,000	49,999,999	1, 3, 4, 5, 6, 12, 13
MO	1	1,000	9,999	1, 5, 14
MS	1	10,000,000	49,999,999	6
NC	1	0	99	6, 7, 8, 11
NE	1	1,000	9,999	9, 12
NJ	2	1,000,000	49,999,999	6, 12

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

State[a]	Number of facilities	Minimum amount on site in pounds[b]	Maximum amount on site in pounds[b]	Activities and uses[c]
NY	1	0	99	12
OH	3	100	9,999	6, 12
TX	12	100	499,999,999	1, 3, 4, 5, 6, 9, 12, 13, 14
UT	1	1,000	9,999	9, 12
WA	1	Not available	Not available	Not available

[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: TRI21 2023a (Data are from 2021)

Table 5-2. U.S. Production Capacity of Vinyl Chloride

U.S. Producer	Location	Capacity (million pounds per year)
Axiall	Plaquemine, Louisiana	CBI
Axiall	Westlake, Louisiana	CBI
Axiall	Westlake, Calcasieu, Louisiana	1,026
C-K Tech	Plaquemine, Louisiana	CBI
Formosa Plastics	Baton Rouge, Louisiana	1,188
Formosa Plastics	Point Comfort, Texas	1,497
GEON Oxy Vinyl	Laporte, Texas	CBI
Olin Blue Cube	Freeport, Texas	CBI
Oxy Vinyls LP	Deer Park, Texas	CBI
Oxychem Ingleside	San Patricio, Texas	CBI
Westlake Vinyls	Geismar, Louisiana	540
Westlake Vinyls	Calvert City, Kentucky	1,316
U.S. total capacity: 10,000 - <20,000 million pounds		

CBI = Confidential Business Information

Source: EPA 2021 (data are from 2015)

5.2.2 Import/Export

One facility reported 37,000 pounds imported in 2015, down from 48,700 pounds in 2014 (EPA 2021); no further import data were located. Export volumes for 2004 and 2005 were 2.367 and 1.88 billion pounds, respectively (ICIS 2006). Current export volumes were not located.

5.2.3 Use

Vinyl chloride is an important industrial chemical because of its wide variety of end-use products and the low cost of producing polymers from it. About 95–99% of the global vinyl chloride capacity is used for the production of PVC and its copolymers; other uses include the production of chlorinated solvents such as 1,1,1-trichloroethane (Dreher et al. 2014; Kielhorn et al. 2000).

Vinyl chloride has been used in the past as a refrigerant, as an extraction solvent for heat-sensitive materials, and in the production of chloroacetaldehyde and methyl chloroform (IARC 2012). In the United States, limited quantities of vinyl chloride were used as an aerosol propellant and as an ingredient of drug and cosmetic products; however, these practices were banned by the EPA in 1974 (IARC 2012; NLM 2023).

5.2.4 Disposal

Since vinyl chloride has been identified by EPA as a hazardous material, its disposal is regulated under the Federal Resource Conservation and Recovery Act (RCRA) (EPA 1993). The Department of Transportation monitors compliance with RCRA (and therefore disposal) (DOT 1993). The recommended method of disposal is total destruction by incineration.

The temperature of the incinerator must be sufficient to ensure the complete combustion of the vinyl chloride in order to prevent the formation of phosgene. The recommended temperature range for incineration is 450–1,600°C, with residence times of seconds for gases and liquids, and hours for solids (NLM 2023). If in solution, the vinyl chloride product may need to be adsorbed onto a combustible material prior to incineration. Alternately, vinyl chloride can also be dissolved in a flammable solvent prior to incineration. An acid scrubber should be used in conjunction with the incinerator in order to remove any hydrogen chloride that is produced by the combustion process (NLM 2023).

Vinyl chloride can also be chemically destroyed. This destruction method is used, especially with small quantities. Generally, 1–2 days is sufficient for complete chemical destruction (NLM 2023).

Aqueous byproduct solutions from the production of vinyl chloride are usually steam-stripped. This step removes volatile organic compounds. The remaining solution is then neutralized. Lastly, the solution is treated in an activated sludge system to remove nonvolatile organic compounds (Cowfer and Gorensek 2006).

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 2022). 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's North American Industry Classification System (NAICS) codes is covered under EPCRA Section 313 or is a federal facility; and if their facility manufactures (defined to include importing) or processes any TRI chemical in excess of 25,000 pounds, or otherwise uses any TRI chemical in excess of 10,000 pounds, in a calendar year (EPA 2022).

5.3.1 Air

Estimated releases of 428,185 pounds (~194 metric tons) of vinyl chloride to the atmosphere from 38 domestic manufacturing and processing facilities in 2021, accounted for about 99.9% of the estimated total environmental releases from facilities required to report to the TRI (TRI21 2023a). These releases are summarized in Table 5-3.

Table 5-3. Releases to the Environment from Facilities that Produce, Process, or Use Vinyl Chloride[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
AL	1	1,820	0	0	0	0	1,820	0	1,820
AR	1	6	0	0	108	0	6	108	114
IL	1	19,115	0	0	21	0	19,115	21	19,135
KY	3	117,526	1	0	0	7	117,526	8	117,534
LA	8	117,553	31	0	1	51	117,584	52	117,636

Table 5-3. Releases to the Environment from Facilities that Produce, Process, or Use Vinyl Chloride[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
MO	1	287	0	0	0	0	287	0	287
MS	1	4,779	0	0	0	0	4,779	0	4,779
NC	1	68	0	0	0	0	68	0	68
NE	1	23	0	0	0	2	23	2	25
NJ	2	24,407	10	0	10	0	24,417	10	24,427
NY	1	0	0	0	0	0	0	0	0
OH	3	10	0	0	0	0	10	0	10
TX	12	142,591	8	0	0	88	142,598	88	142,686
UT	1	0	0	0	0	0	0	0	0
WA	1	0	0	0	0	0	0	0	0
Total	38	428,185	49	0	140	148	428,233	289	428,522

[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: TRI21 2023a (Data are from 2021)

The major sources of vinyl chloride releases to the environment are believed to be emissions and effluents from plastic industries, primarily vinyl chloride and PVC manufacturers. Due to modifications in the PVC manufacturing process, decreases in emissions of vinyl chloride have been achieved over the past several decades. According to data from the TRI, total air emissions of vinyl chloride were reported as 885,387 pounds in 1998 but have declined to 428,184 pounds in 2021 (TRI21 2023a).

EPA’s National Emission Inventory (NEI) database contains detailed information about sources that emit criteria air pollutants and their precursors, and hazardous air pollutants (HAPs) for the 50 United States, Washington DC, Puerto Rico, and the U.S. Virgin Islands. In 2011, there were 920,128 pounds of vinyl chloride released to air from 15 different emissions categories, the most prominent being waste disposal and industrial processes, accounting for roughly 30 and 60% of all of the emissions, respectively (EPA 2014). Over an 11-year emission study within the Greater Houston area, spanning from 2003 to 2013, vinyl chloride was released in an emission event at a high of 6,520 kg in 2005 from Dow Texas Operations Freeport (Luong and Zhang 2017). This event contributed 99% of the emissions for that year. Vinyl chloride detected at hazardous waste sites may not necessarily arise from industrial sources. The bacterial degradation of chlorinated solvents such as trichloroethylene, tetrachloroethylene, 1,1,1-trichloroethane, and cis-dichloroethene can produce vinyl chloride as a degradation product, and this may be the origin of vinyl chloride at these sites (Smith and Dragun 1984; Xiao et al. 2020).

Ahn et al. (2020) estimated that concentrations of 45.5 $\mu g/m^3$ (17.8 ppbv) vinyl chloride could have been released into the air from soil at nighttime as a result of the release of 43,780 kg of volatile organic compounds (VOCs) from an oil refinery in Texas after Hurricane Harvey in Houston in August 2017, with daytime emissions estimated to be 10 times lower. This value was based on modeling data of mineral-type soils under water-saturated conditions (67% soil-water content at 25°C), and an estimated soil-air partition coefficient (K_{SA} 4.60) and an octanol-air partition coefficient (log K_{oa} 0.92) for vinyl chloride.

Five vinyl chloride monomer tank cars carrying 115,580 gallons of vinyl chloride were derailed in the Norfolk Southern Railway Train Derailment on February 3, 2023, in East Palestine, Ohio (National Transport Safety Board 2023). To avoid an explosion hazard of the tank cars, controlled venting was performed to release and burn the vinyl chloride. Venting took place for several hours beginning on February 6, 2023. Released liquid vinyl chloride was contained in ditches dug by responders while it vaporized and burned.

5.3.2 Water

Estimated releases of 49 pounds (~0.02 metric tons) of vinyl chloride to surface water from 38 domestic manufacturing and processing facilities in 2021, accounted for about 0.01% of the estimated total environmental releases from facilities required to report to the TRI21 (TRI21 2023a). This estimate includes releases to wastewater treatment and publicly owned treatment works (POTWs) (TRI21 2023a). These releases are summarized in Table 5-3.

Vinyl chloride released in wastewater from the plastics industries is expected to volatilize fairly rapidly (on the order of hours to days) into the atmosphere. Anaerobic reductive dehalogenation of trichloroethylene, tetrachloroethylene, and 1,1,1-trichloroethane also releases vinyl chloride into groundwater at hazardous waste sites (Smith and Dragun 1984) or other locations where the proper conditions are found in the subterranean strata. Since vinyl chloride possesses high mobility in soils, it leaches into groundwater from spills, landfills, and industrial sources that may release it to soil (TRI21 2023a). According to data collected from the analysis of leachates and monitoring wells at sites where groundwater was contaminated by municipal solid waste landfill leachate, vinyl chloride was present in both the leachates and the groundwater samples (Sabel and Clark 1984).

5.3.3 Soil

Estimated releases of 140 pounds (~0.06 metric tons) of vinyl chloride to soil from 38 domestic manufacturing and processing facilities in 2021, accounted for about 0.03% of the estimated total environmental releases from facilities required to report to the TRI21 (TRI21 2023a). These releases are summarized in Table 5-3.

The bacterial degradation of chlorinated solvents such as trichloroethylene, tetrachloroethylene, 1,1,1-trichloroethane, and cis-dichloroethene can produce vinyl chloride as a degradation product, and this may be a significant source of vinyl chloride at contaminated and hazardous waste sites (Smith and Dragun 1984; Xiao et al. 2020).

5.4 ENVIRONMENTAL FATE

5.4.1 Transport and Partitioning

Air. Based on a vapor pressure of 2,660 mmHg at 25°C, essentially all vinyl chloride in the atmosphere is expected to exist solely as a gas (Eisenreich et al. 1981; Verschueren 1983). Consequently, removal from the atmosphere by dry deposition is not expected to be an important fate process.

Water. The primary transport process for vinyl chloride from natural water systems is volatilization into the atmosphere. The Henry's law constant of vinyl chloride has been measured as 0.0278 atm-m^3/mol at 24.8°C (Gossett 1987), which suggests that vinyl chloride should partition rapidly to the atmosphere. The half-life for vinyl chloride volatilization from a typical pond, river, and lake has been estimated to be

43.3, 8.7, and 34.7 hours, respectively. These values are based on an experimentally determined reaeration rate ratio of approximately 2 and assumed oxygen reaeration rates of 0.008, 0.04, and 0.01 per hour for a typical pond, river, and lake, respectively (EPA 1982a).

Predicted half-lives should be considered rough estimates since the presence of various salts in natural water systems may affect the volatility of vinyl chloride significantly (EPA 1979). Many salts can form complexes with vinyl chloride and increase its water solubility; therefore, the presence of salts in natural waters may significantly influence the amount of vinyl chloride remaining in the water (EPA 1975). The half-life of vinyl chloride in bodies of water is also affected by depth and turbidity.

The uptake of vinyl chloride by trees from groundwater was examined by sampling and analyzing tree trunk matrices for the uptake of vinyl chloride in four sampling events at two sites with known contamination in groundwaters, the “Caretti site” (Ferrara, Emilia-Romagna Region) and the “Bussi site” (Bussi sul Tirino, Pescara, Abruzzo Region) to assess the potential for vapor intrusion (Filippini et al. 2022). In May 2019, vinyl chloride was detected in groundwater at concentrations of 3,550.0–7,181.0 µg/L and in trunk cores at below the detection limit to 33.0 µg/kg; in October 2019, vinyl chloride was detected in groundwater at concentrations of 110.0–1649.0 µg/L and in trunk cores at 3.0–13.0 µg/kg; in June 2020, vinyl chloride was detected in groundwater at concentrations of 164.0–2,230.0 µg/L and in trunk cores at 1.6 to 19.7 µg/kg; and in September 2020, vinyl chloride was detected in groundwater at concentrations of 119.0–1,529.0 µg/L and in trunk cores in concentrations that were below the limit of detection (LOD).

Sediment and Soil. The relatively high vapor pressure of vinyl chloride indicates that this compound volatilizes rapidly from dry soil surfaces (Verschueren 1983). Volatilization from soil is affected by several factors, including temperature and soil characteristics (Ahn et al. 2020; Rossabi et al. 2018). The effective half-life (due to volatilization and degradation) of vinyl chloride incorporated 10 cm deep in dry soil is predicted to be 12 hours (Jury et al. 1984). Vinyl chloride is soluble in water and can therefore leach through the soil and enter groundwater before evaporation can occur (Cowfer and Gorensek 2006).

The soil organic carbon adsorption coefficient (K_{oc}) for vinyl chloride was determined to range from 240 to 890 in seven natural clayey till samples (Lu et al. 2011). These K_{oc} values suggest a low sorption tendency, meaning that this compound would be highly mobile in soil. Thus, vinyl chloride has the potential to leach into groundwater.

Other Media. Vinyl chloride is soluble in most common organic solvents (Cowfer and Gorensek 2006). In situations where organic solvents exist in relatively high concentrations (e.g., landfills, hazardous waste sites), co-solvation of vinyl chloride could reduce its volatility, thus causing it to have greater mobility than indicated by measured K_{oc} values.

Vinyl chloride's low octanol/water partition coefficient (log K_{ow} of 1.23) indicates that the potential for bioconcentration in aquatic organisms is low (EPA 1982a). Using a log K_{ow} of 1.23 and a regression-derived equation (Meylan et al. 1999), the bioconcentration factor (BCF) for vinyl chloride is estimated as 3. Freitag et al. (1985) measured BCFs for vinyl chloride in algae, fish, and activated sludge. The vinyl chloride BCFs for algae, fish, and activated sludge were 40, <10, and 1,100, respectively. The very low value for fish, in comparison to the algae and activated sludge, may suggest a detoxification process in more highly developed organisms such as fish. Lu et al. (1977) examined the bioaccumulation of ^{14}C-vinyl chloride in a closed model aquatic ecosystem over a 3-day period. The high volatility of vinyl chloride minimized any potential bioaccumulation. The relatively low tissue concentrations found in fish suggest that vinyl chloride is not biomagnified in aquatic food chains to any substantial degree.

5.4.2 Transformation and Degradation

Air. Reaction of gaseous vinyl chloride with photochemically generated hydroxyl radicals is predicted to be the primary degradation mechanism for this compound in the atmosphere (Cox et al. 1974; Howard 1976; Perry et al. 1977). The rate constant for this reaction was measured as 6.96×10^{-12} cm^3/molecule-second (Kwok and Atkinson 1995). This rate constant corresponds to an atmospheric half-life of about 18 hours assuming a hydroxyl radical concentration of 1.5×10^6 molecules/cm^3. Products of this reaction are hydrochloric acid, formaldehyde, formyl chloride, carbon monoxide, carbon dioxide, chloroacetaldehyde, acetylene, chloroethylene epoxide, chloroacetylchloranil, and water (Müller and Korte 1977; Woldbaek and Klaboe 1978). Under conditions of photochemical smog and increased nitric oxide (NO) concentrations, the half-life of vinyl chloride has been shown to be reduced to 1.2–4.2 hours, depending on both vinyl chloride and NO concentrations (Carassiti et al. 1977). Reaction of vinyl chloride with ozone and nitrate radicals in the atmosphere is expected to be slow; half-lives of ca. 45 and 37 days can be expected based on the ozone reaction rate constant of $2.45 \pm 0.45 \times 10^{-19}$ cm^3/molecule-second and the nitrate radical reaction rate constant of 4.3×10^{-16} cm^3/molecule-second, respectively (Atkinson 1991; EPA 1976, 1985b; Zhang et al. 1983). Direct photolysis is not expected to be an important degradation mechanism in the atmosphere because vinyl chloride in the gas phase does not absorb light of wavelengths above 220 nm (EPA 1976). Since atmospheric ozone blocks almost all sunlight with wavelengths <295 nm, direct photolysis is likely to occur very slowly, if at all, in the atmosphere (EPA 1976).

Water. The primary removal process for vinyl chloride from surface waters is volatilization into the atmosphere. Vinyl chloride in water does not absorb ultraviolet radiation above 218 nm; therefore, direct photolysis in the aquatic environment is expected to occur very slowly, if at all (EPA 1976). In sunlit surface waters containing photosensitizers, such as humic materials, photodegradation may be more rapid. If so, in some waters, sensitized photodegradation may be an important removal mechanism (EPA 1976). Vinyl chloride decomposed rapidly when irradiated with ultraviolet light in the presence of acetone, a high energy triplet sensitizer, or hydrogen peroxide, a free radical source (EPA 1976).

The hydrolytic half-life of vinyl chloride is estimated to be <10 years at 25°C (EPA 1976). Since the volatilization rate of vinyl chloride is much more rapid than the predicted rate of hydrolysis, hydrolysis is not a significant aquatic fate (EPA 1976, 1979). Vinyl chloride is not oxidized chemically by reaction with photochemically generated molecular oxygen in natural water systems (EPA 1976). Experiments carried out at 20 mg/L vinyl chloride in water saturated with molecular oxygen at elevated temperatures showed that, after 12 hours at 85°C, no degradation of vinyl chloride was observed. At temperatures and oxygen concentrations in natural waters, therefore, vinyl chloride is not expected to degrade by molecular oxygen at a significant rate (EPA 1976).

Biodegradation of vinyl chloride in water typically occurs via three important pathways: (1) anaerobic reductive dichlorination producing ethene; (2) anaerobic oxidation to carbon dioxide under iron or manganese reducing conditions; and (3) aerobic ultimate biodegradation to carbon dioxide (SERDP/ESTCP 2012). The degradation of vinyl chloride under anaerobic conditions was studied using iron-enriched aquifer microcosms obtained from a site contaminated with various chlorinated compounds (Smits et al. 2011). Two separate microcosm columns were prepared in which one column was fed solely vinyl chloride while the second column had both vinyl chloride and acetate in the influent. Degradation of vinyl chloride and formation of ethene was noticeable in the vinyl chloride and acetate influent column. This suggests a reductive dichlorination pathway for vinyl chloride degradation; however, ethene was not produced in the column where vinyl chloride was the only substance in the influent, suggesting that oxidation to carbon dioxide was the important degradation pathway in this column.

Vinyl chloride (1 ppm) was rapidly degraded under aerobic conditions in a laboratory study that used soil-water microcosms from aquifer material without the addition of other nutrients, such as nitrogen or phosphorus (Davis and Carpenter 1990). About 25% of the vinyl chloride was degraded after 1 week and >99% was degraded after 108 days. Sixty-five percent of labeled vinyl chloride was recovered as $^{14}CO_2$ after 108 days, demonstrating the extent of the mineralization.

Multiple vinyl chloride degrading bacteria have been isolated and demonstrate capacity to degrade vinyl chloride under aerobic conditions (Coleman and Spain 2003; Coleman et al. 2002; Danko et al. 2006; Zalesak et al. 2021). *Rhodococcus* sp. Strain SM-1, a member of the order *Actinomycetales*, obtained from a trichloroethylene-degrading consortium was found to degrade vinyl chloride to CO_2 by using propane as an energy source during growth experiments or cell suspension experiments (Phelps et al. 1991). Vinyl chloride concentrations decreased by more than 90%; growth cultures and cell suspensions incorporated about 10% of the transformed vinyl chloride into biomass (Phelps et al. 1991). *Mycobacterium vaccae* JOB5 degraded 100% of vinyl chloride in a 2-hour incubation (Wackett et al. 1989). In sediment and groundwater microcosms constructed from a contaminated site containing ethenotrophic bacteria, biodegradation of vinyl chloride was observed under fully aerobic (dissolved oxygen >8 mg/L), limited oxygen, and low oxygen conditions (dissolved oxygen of <1 mg/L) with 22–24% removal after 110 days, 74% removal after 110 days, and 100% removal after 62 days, respectively (Richards et al. 2022).

Degradation of vinyl chloride generally occurs slowly in anaerobic groundwater and sediment; however, under methanogenic or Fe(III)-reducing conditions, anaerobic degradation occurs more rapidly. Vinyl chloride was mineralized approximately 34% in 84 hours in anaerobic aquifer microcosms supplemented with Fe(III) and held under Fe(III)-reducing conditions (Bradley and Chapelle 1996). Reductive dechlorination of vinyl chloride to ethene was observed in enrichment cultures containing *Dehalococcoides* as the dominant species, along with *Acetobacterium* and *Sporomusa* (Puentes Jacome et al. 2019). Dechlorination rates of 2.0–8.8 µmol Cl^- released/L/day were reported at pH values ranging from 5.5 to 7.0 after an incubation period of ca. 400 days, with slower rates observed at the lowest pH of 5.5.

Sediment and Soil. Most vinyl chloride present on soil surfaces will volatilize to the atmosphere. Vinyl chloride is also mobile in soil and susceptible to leaching (Lyman et al. 1982). Because vinyl chloride is soluble in organic solvents (Cowfer and Gorensek 2006), the presence of other organic solvents, such as those found at hazardous waste sites, may affect the mobility of the substance in the soil. Photodegradation on the surface of soils is possible since sensitized photodegradation in water occurs;

however, this is not expected to be an important environmental fate process for vinyl chloride in most soils and sediment.

Several laboratory studies indicated that both aerobic and anaerobic biodegradation of vinyl chloride can occur in soils and aquifer materials via a number of mechanisms (Barrio-Lage et al. 1990; Castro et al. 1992a, 1992b; Davis and Carpenter 1990), although these degradation processes were generally slow. Nelson and Jewell (1993) investigated methanotrophic degradation of vinyl chloride using a laboratory-scale, methanotrophic, attached-film, expanded-bed bioreactor. The study authors found that this technique is an efficient way to degrade vinyl chloride, with the removal efficiency >90%. Under methanotrophic conditions, vinyl chloride was mineralized between 5 and 44% over 37 days using creek bed sediment microcosms obtained from a naval station near Jacksonville, Florida (Bradley and Chapelle 1997). Slightly higher mineralization rates were observed under Fe(III)-reducing conditions. With vinyl chloride-oxidizing transfer cultures and microcosms derived from authentic site materials, vinyl chloride oxidation was sustained at what can be considered anaerobic conditions with dissolved oxygen concentrations below 0.02 and 0.1 mg/L, respectively (Gossett 2010). Vinyl chloride was degraded approximately 50 and 100% in 25 and 19 days under these respective conditions (Gossett 2010).

5.5 LEVELS IN THE ENVIRONMENT

Reliable evaluation of the potential for human exposure to vinyl chloride depends, in part, on the reliability of supporting analytical data from environmental samples and biological specimens. Concentrations of vinyl chloride 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 vinyl chloride 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.

The EPA maintains a Water Quality Portal (WQP) database that aggregates environmental monitoring data from the National Water Information System (NWIS) and STORage and RETrieval (STORET) system. Summaries of the data for ambient surface and groundwater from recent years are presented in Tables 5-4 and 5-5. Based on limited sampling, vinyl chloride has been detected most frequently in groundwater, with limited detections in sediments and soil. Detections were generally at or below reporting limits, and the highest concentrations were found in groundwater samples (WQP 2021, 2023).

Table 5-4. Vinyl Chloride Detected in Samples Collected Throughout the United States from 2011 to 2021

Type	Number of samples	Number of positive	Concentration range
Ambient air	58	0	0.039–0.052 ppb (detection limit)
Indoor air	4	0	0.039–0.052 ppb (detection limit)
Groundwater[a]	6,838	254	0.2–7,380 ppb; 0.1–20 ppb (lower quantification limit)
Surface water[a]	1,358	0	<0.02–5.0 ppb (lower quantification limit)
Wastewater	2	0	0.1 ppb (lower quantification limit)
Leachate	48	0	0.5–1.0 ppb (lower quantification limit)
Sediment	306	1	1,300 ppb; 0.5–1,000 ppb (lower quantification limit)
Soil	45	4	2.4–9.6 ppb (values are below reporting limit)

[a] Samples reported are from 2017 to 2021.

Source: WQP 2021

Table 5-5. Vinyl Chloride Detected in Samples Collected Throughout the United States in 2022 and 2023[a]

Type	Number of samples	Positive detections (%)	Average concentration (maximum)
Ambient air	0	0	Not applicable
Ambient air at Superfund site	10	0	Not detected (method detection limit 0.039–0.059 ppb [0.1–0.15 µg/m^3])
Ambient groundwater[a]	2,674	1.0	2022: 12.4 µg/L or ppb (61.3 µg/L or ppb) 2023: 6.79 µg/L or ppb (7.71 µg/L or ppb)
Ambient groundwater at Superfund site	226	0	Not detected (method detection limit 0.06–2,000 µg/L or ppb)
Surface water	69	1.4	2022: 0.5 µg/L or ppb (0.5 µg/L or ppb) 2023: not detected (method detection limit 0.06–1 µg/L)
Surface water at Superfund site	4	0	Not detected (method detection limit 0.2 µg/L or ppb)
Sediment	0	0	Not applicable
Sediment at Superfund site	0	0	Not applicable

Table 5-5. Vinyl Chloride Detected in Samples Collected Throughout the United States in 2022 and 2023[a]

Type	Number of samples	Positive detections (%)	Average concentration (maximum)
Soil	0	0	Not applicable
Soil at Superfund site	28	0	Not detected (method detection limit 0.00045–0.0011 mg/kg)

[a]Samples reported are from January 2022 through June 2023.

Source: WQP 2023

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

Table 5-6. Vinyl Chloride 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
Water (ppb)	34	55.9	17.1	505	266
Soil (ppb)	733	962	34.1	45	38
Air (ppbv)	1.6 (4.09 μg/m^3)	3.25 (8.31 μg/m^3)	26.4 (67.5 μg/m^3)	56	37

[a]Concentrations found in ATSDR site documents from 1981 to 2022 for 1,868 NPL sites (ATSDR 2022). 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 in rural/remote and urban/suburban areas of the United States typically contains very low or no detectable amounts of vinyl chloride (EPA 1982b; Grimsrud and Rasmussen 1975a, 1975b; Harkov et al. 1984; Pratt et al. 2000; Stephens et al. 1986; Wallace et al. 1984). In a background air toxics concentration study for North America conducted in 2001–2002, vinyl chloride concentrations were estimated to be <0.02 μg/m^3 (<0.0075 ppbv) (McCarthy et al. 2006). In a residential region of Southwest Memphis surrounded by fossil fuel burning, steel, refining, and food processing industries, vinyl chloride was found in 38% of 103 samples at a mean concentration of 0.02 μg/m^3 (Jia and Foran 2013).

Concentrations in air samples collected in 2000–2017 at Denton Airport South, Texas (in close proximity to the Barnett Shale location) were reported as 0.02–0.08 parts per billion carbon, which is equivalent to

0.01–0.04 ppbv and in 19 positive detections out of 1,085 samples (Lim and John 2020). Vinyl chloride was not detected (detection limit 0.1–0.14 μg/m^3) in 58 ambient air or 4 indoor air data points compiled for 2011–2021 from Palermo Wellfield Superfund Site, as reported in the EPA STORET database (WQP 2021). Based on limited sampling, vinyl chloride was not detected in ambient air samples collected in 2022 through June of 2023 from the WQP database (WQP 2023).

Vinyl chloride levels in atmospheric samples collected across the United States are available from the Air Quality System (AQS), which is the EPA's repository of ambient air quality data that has >5,000 active monitors nationwide (EPA 2023c). The vinyl chloride levels have remained fairly consistent over the period of 2020–2022 as indicated by data summarized in Table 5-7.

Table 5-7. Summary of Annual Concentrations of Vinyl Chloride in ppbv Measured in Ambient Air at Locations Across the United States[a]

Year	Number of monitoring locations	Number of observations	Range of arithmetic mean	Maximum
2022	94	10,339	<LOD–0.68	6.05
2021	97	10,925	<LOD–0.68	6.05
2020	92	8,123	<LOD–0.88	5.40

[a] Values initially reported in ppbC but converted to ppbv.

LOD = limit of detection

Vinyl chloride concentrations were reported at 0.12–12 μg/m^3 (0.047–4.56 ppbv) for flowback pits used to store natural gas drilling hydraulic fracturing waste (Bloomdahl et al. 2014).

Monitoring of vinyl chloride levels in ambient air has been conducted in response to the East Palestine, Ohio Train Derailment, which occurred on February 3, 2023. Real-time air monitoring began on February 4, 2023, in 12 locations surrounding the fire and in neighboring communities (EPA 2023a, 2023e). All final samples were analyzed according to the EPA Toxic Organics-15 (TO-15) selected ion-monitoring mode (SIM) method. TO-15 has reporting limits ranging from 0.029 to 0.074 μg/m^3 (EPA 1999). Of the 644 validated samples collected through June 7, 2023, in which vinyl chloride was detected, there were 427 detections between February 6 and May 16, 2023 that were above the method reporting limit, with concentrations ranging from 0.035 to 16 μg/m^3 (0.013–6.08 ppbv), an average of 0.69 μg/m^3, and a median value of 0.32 μg/m^3 (EPA 2023b, EPA 2023d).

5.5.2 Water

Vinyl chloride has been detected at varying concentrations in surface water, groundwater, and drinking water throughout the United States (Tables 5-4 and 5-5). Vinyl chloride was not reported above the lower quantification limit of 0.02–5.0 μg/L (ppb) in approximately 1,360 ambient surface water samples as reflected in data points compiled for 2017–2021 from EPA's STORET and NWIS databases (WQP 2021). Vinyl chloride was detected in approximately 2.3% of 43 surface water samples in 2022 at average concentrations of ca. 0.5 ppb (maximum of 0.5 ppb) and was not detected in 26 surface water samples collected through April 2023 (WQP 2023). Vinyl chloride was not detected in four samples of surface water collected at Palermo Wellfield Superfund Site in 2022 (WQP 2023). Vinyl chloride was detected in approximately 1% of 2,385 groundwater samples in 2022 and approximately 1% of 289 groundwater samples collected through April 2023 at average concentrations of ca. 12.4 ppb (maximum of 61.3 ppb) and ca. 6.8 ppb (maximum of 7.7), respectively (WQP 2023). Vinyl chloride was not detected in 226 samples of groundwater collected at Palermo Wellfield Superfund Site in 2022 (WQP 2023).

During an assessment of groundwater in the United States from 1985 to 2001, vinyl chloride was detected at a median concentration of 1.1 μg/L (positive detections only) in samples obtained from >50 of the nation's most important river basins and aquifers (USGS 2006). It was also detected in 0.083% of 2,401 samples of domestic wells at a level of 0.20 μg/L and in 0.042% of samples at a level of 1 μg/L. Vinyl chloride was not detected in any samples at assessment levels >5 μg/L. The median level of vinyl chloride in these domestic wells (positive detections only) was 0.74 μg/L (USGS 2006). Bexfield et al. (2022) summarized groundwater monitoring results from 1,531 wells and 6 springs sampled between 2013 to 2019 and found that vinyl chloride was detected most commonly in anoxic groundwater. Based on the maximum contaminant level (MCL) of 2.0 μg/L, two wells had a benchmark quotient (BQ) of >0.1 (maximum of 0.19), which accounted for an area proportion of <0.01% and none of the wells had concentrations of vinyl chloride that resulted in a BQ of >1, indicating that vinyl chloride was not detected above 2.0 μg/L in any samples.

Vinyl chloride was detected in 6 out of 518 monitoring wells sampled in 19 urban land-use watersheds in the United States during a U.S. Geological Survey (USGS) analysis of groundwater contaminants conducted from 1996 to 2002 (Squillace et al. 2004). The median level was reported as 0.2 μg/L and the maximum concentration was 8.1 μg/L. Vinyl chloride was found in 1.12% of 448 groundwater supply wells monitored from 2002 to 2009 across the United States at an assessment level of 0.05 μg/L and in

0.89% of samples at an assessment level of 0.10 µg/L (USGS 2014). Vinyl chloride was detected in 254 of 6,838 (3.7%) groundwater data points compiled for 2017 to 2021 from EPA STORET and NWIS databases at concentrations of 0.2 to 7,380 µg/L (WQP 2021). This includes data from hazardous waste sites.

Vinyl chloride was detected at levels ranging from 11 to 23 ng/L in water samples collected from 15 PVC or chlorinated polyvinyl chloride (CPVC)-utilizing homes located in Ithaca, New York (Walter et al. 2011). Most of the samples obtained from the homes tested negative for vinyl chloride, but each of the positive detections occurred from homes using municipal (chlorinated) water and CPVC type pipe. A report compiled by NSF International on the amount of vinyl chloride monomer measured during certification testing of drinking water systems from January 1998 through October 2000 indicated that there were no detectable levels (≥0.1 mg/kg) of vinyl chloride in 445 of 519 PVC pipe samples or 157 of 178 PVC fittings (Borrelli et al. 2005). The average residual vinyl chloride monomer found was 0.07 mg/kg in pipes tested and 0.03 mg/kg in the fittings tested when considering non-detects as zero. During an assessment of drinking water sources from 2002 to 2010, vinyl chloride was not detected in 300 samples from 20 surface water sites across the United States (USGS 2014).

In a study of three landfills located in Orange County, Florida, vinyl chloride was detected in water samples obtained at four of nine wells with average concentrations ranging from 2.0 to 26.5 µg/L (Hallbourg et al. 1992). Vinyl chloride levels in 50 domestic wells located distal and proximal to shale-gas wells in upland areas of Marcellus Shale region of New York and Pennsylvania were <0.06 µg/L (ppb) (McMahon et al. 2019).

A groundwater monitoring study assessing correlation of household water from wells and springs near active unconventional oil and gas (UOG) wells was conducted in the Appalachian Basin where active UOG wells were present between July and September 2018 (Bradford County, Pennsylvania) or May to August 2019 (Belmont and Monroe Counties, Ohio). Water samples were collected upstream from home water treatment/filtration systems (Clark et al. 2022). The study authors reported that vinyl chloride was detected above the LOD in 26% of Pennsylvania samples, with the median concentration below the LOD and the interquartile range of <LOD–0.0004 µg/L (limit of quantification [LOQ] defined as 0.047 µg/L; EPA method 624); in Ohio samples, 57% of detections were greater than the LOD; the median concentration was 0.003 µg/L with the interquartile range of <LOD–0.023 µg/L (LOQ defined as 0.046 µg/L; EPA method 624). Based on spatial surrogate analysis there was no correlation observed with proximity or distance to the nearest UOG well.

Monitoring of vinyl chloride levels in water has been conducted in response to the East Palestine, Ohio Train Derailment, which occurred on February 3, 2023. Surface water monitoring was conducted in nearby creeks including Sulphur Run, Leslie Run, and waterways downstream of the Ohio River. All final samples have been analyzed according to EPA method 8260D (EPA 2023a, 2023e), with a reporting limit of 1 or 100 µg/L, or 0.27 mg/kg (EPA 2018a). Of the 14 validated samples collected through June 7, 2023, in which vinyl chloride was detected on February 8 and 10, 2023, there were six detections above the method reporting limit with concentrations ranging from 1.1 to 2400 µg/L and one detection listed as the free product in surface water at a concentration of 0.65 mg/kg (EPA 2023d, 2023f). Treated drinking water samples tested did not show detections of vinyl chloride.

The majority of drinking water supplies in the United States do not contain detectable levels of vinyl chloride (Borrelli et al. 2005; EPA 1982b; Westrick et al. 1984). As part of the Safe Drinking Water Act (SDWA), EPA reviews each national primary drinking water regulation at least once every 6 years and make revisions if necessary. Vinyl chloride monitoring data from public water supplies in the United States as part of the 6-year reviews (1998–2005 and 2006–2011) is shown in Table 5-8 (EPA 2016).

Table 5-8. Safe Drinking Water Act (SDWA) 6-Year Reviews (1998–2005 and 2006–2011)

	1998–2005	Percent of totals for 1998–2005	2006–2011	Percent of totals for 2006–2011
Total number of samples	373,161	100	368,740	100
Total number of samples with detection >0.5 µg/L	550	0.15	725	0.20
Total number of samples with detection >2 µg/L	107	0.03	125	0.03
Average of samples with detection >0.5 µg/L	1.8		2.3	
Average of samples with detection >2 µg/L	6.2		8.9	

Source: EPA 2016

A U.S. survey that combined drinking water contaminant occurrence for all 50 states (2014–2019) and 5-year (2015–2019) population estimates from the U.S. Census Bureau's American Community Survey detected vinyl chloride in 122 out of 47,820 community water systems, with an average concentration of 0.5 ng/L. The U.S. population served by these systems is 2.1 million, which corresponds to a population-weighted average contaminant concentration of 1.8 ng/L or 0.0018 µg/L (Uche et al. 2021).

5.5.3 Sediment and Soil

Data (Table 5-4) from the EPA Great Lakes National Program reported vinyl chloride in one (1,300 ppb) of 212 sediment samples collected in 2011–2021 at a level above the quantification or reporting limit of 1.2–7,300 ppb (WQP 2021). Vinyl chloride was not detected (detection limit not reported) in sediment samples at any other sites reported in the EPA STORET database. Vinyl chloride was detected in 4 of 45 soil data points reported for 2011–2021 and included in the EPA STORET database, but not at levels above the lower reporting level of 9.4–38 ppb (WQP 2021).

Monitoring of vinyl chloride levels in soil and sediment has been conducted in response to the East Palestine, Ohio Train Derailment, which occurred on February 3, 2023. Soil and sediment samples were collected at the derailment site. Soils were sampled at four locations near derailed train cars, which contained hazardous materials, and sediments were sampled in two locations near the Sulphur Run stream. All final samples were analyzed according to the EPA method 8260D (EPA 2023a, 2023e), with reporting limits ranging from 0.0064 to 9 mg/kg (EPA 2018a). Of the nine validated samples collected through June 7, 2023, in which vinyl chloride was detected, there were four detections on February 8th and 10th, 2023 (soil n=3; sediment n=1) above the method reporting limit with concentrations ranging from 3.9 mg/kg (soil) to 11 mg/kg (sediment) (average of 6.1 mg/kg, median of 4.8 mg/kg) (EPA 2023d, 2023g). Vinyl chloride was not detected above the method limits in sediment or soil samples collected in 2022 or 2023 at the Palermo Wellfield Superfund Site (WQP 2023).

5.5.4 Other Media

In the past, vinyl chloride was detected in various foods and bottled drinking water samples as a result of migration from PVC food wrappings and containers (Benfenati et al. 1991; Gilbert et al. 1980). The Food and Drug Administration (FDA) regulates the use of PVC polymers in food packaging materials and the amount of residual monomer in polymers and as a result, there has been a significant reduction in the reported levels of vinyl chloride in food samples based on data collected since the early 1970s (WHO 1999). Since the late 1970s, modifications to the vinyl chloride and PVC manufacturing and production processes have greatly reduced the amount of residual vinyl chloride monomer in food packaging and other PVC-related items.

To determine whether the residual vinyl chloride levels in PVC containing food packages in current use are <10 ppb, a survey and analysis of PVC-containing food packages were conducted (McNeal et al.

2003). The results showed that vinyl chloride levels found in the packages ranged from none detected (<1 ppb) to about 275 ppb. The package containing 275 ppb residual vinyl chloride was not a food contact material (McNeal et al. 2003). The Vinyl Institute presented results from an effort to assess residual vinyl chloride monomer in food and non-food packaging materials that demonstrated that all but one of the materials had residual levels <5 ppb; one sample from a plastic bottle of Turkish olive oil was found to contain 28.3 ppb residual vinyl chloride monomer of which 0.6 ppb was identified in the oil contained therein (Borrelli et al. 2005).

Dietary exposure to vinyl chloride from PVC packages used for food was estimated by several agencies and based upon estimated average intakes in the United Kingdom and the United States, an exposure of <0.0004 μg/kg/day was estimated for the late 1970s and early 1980s (WHO 1999). Because vinyl chloride levels in food and drinking water are now well below detection limits, exposure levels from ingestion are expected to be even lower.

Vinyl chloride at concentrations of 0.55–3.32 ppb (1.4–8.49 $\mu g/m^3$) have been identified in the VOC profile of surgical smoke samples collected from breast surgeries with the highest level of 3.32 ppb (8.49 $\mu g/m^3$) observed when using conventional electrosurgical knives and levels ranging from 0.6 to 1.62 ppb (1.5–4.14 $\mu g/m^3$) when using other electrosurgical units (Cheng et al. 2021).

Vinyl chloride was identified as a constituent of chicken manure wastewater emissions at concentrations of 3.8±0.20 ppm (9.7 mg/m^3); the samples were collected from the influent of an anaerobic lagoon at a chicken farm wastewater treatment plant in northern Thailand (Fakkaew et al. 2022).

Vinyl chloride has been detected in tobacco smoke. Cigarette smoke and smoke from small cigars was found to contain 5.6–27.3 ng vinyl chloride per cigarette (Hoffmann et al. 1976). The study authors suggested that the inorganic chloride concentrations in the tobacco determine the amount of vinyl chloride formed upon combustion of tobacco and released with the smoke (Hoffmann et al. 1976). Vinyl chloride was detected in cigarette smoke at levels ranging from 6.31 to 8.04 ng per cigarette for Electrically Heated Cigarette Smoking Systems (EHCSS) and <12.4–18.0 ng per cigarette for conventional lit-end cigarettes in a test using three versions of an EHCSS and four different brands of conventional cigarettes under International Organization for Standardization smoking conditions (Zenzen et al. 2012). When additional smoking regiments were utilized, smoke from conventional cigarettes was found to contain vinyl chloride up to 34.8 ng per cigarette.

Gas emissions from household aerosol products purchased from retail stores in Japan in 2017 (n=38 spray paints) and 2021 (n=1 coating agent) were evaluated for the presence of vinyl chloride (Sugaya et al. 2023). Vinyl chloride was identified in the emissions of 3 out of 39 products tested at concentrations of 0.095, 0.098, and 0.28 μg/L (method LOQ = 0.095 μg/L).

5.6 GENERAL POPULATION EXPOSURE

A review of vapor intrusion data from 148 ATSDR public health assessments completed between 1994 and 2009 identified 42 sites with detected concentrations of vinyl chloride in groundwater, soil gas, or air (Burk and Zarus 2013). Indoor air was sampled at 13 of the sites, with vinyl chloride detected at levels ranging from 0.021 to 35 μg/m^3, which are all below ATSDR's inhalation MRLs (50–1,300 mg/m^3). Vinyl chloride was detected in groundwater at 31 of the sites ranging from 0.148 to 27,000 μg/L, and 14 of the sites had vinyl chloride groundwater concentrations at levels of concern from noncancer effects from vapor intrusion. Twelve of the 14 sites with groundwater concentrations at levels of concern from noncancer effects from vapor intrusion did not report measured indoor air concentrations for vinyl chloride.

Vinyl chloride in water is expected to rapidly volatilize; thus, there is potential for inhalation exposure during showering and bathing, and during other household water uses. ATSDR's three-compartment Shower and Household-Use Exposure (SHOWER) model predicts air concentrations in the shower stall, bathroom, and main house throughout the day by estimating the contribution from showering or bathing and the contribution from other water sources in the house, such as the dishwasher, clothes washer, and sink faucets. This information along with human activity patterns are used to calculate a daily time-weighted average exposure concentration via inhalation exposure and from dermal uptake from skin contact. ATSDR's SHOWER model is available by sending a request to showermodel@cdc.gov. Table 5-9 displays the calculated reasonable maximum exposure (RME) levels for groups exposed to vinyl chloride using the most conservative representative treated water levels (0.0018 μg/L; Uche et al. 2021) from Section 5.5.2 and representative outdoor air levels (0.68 ppb; EPA 2023c) in Section 5.5.1. For a 15-minute exposure time, the SHOWER model predicts that the average human exposure concentration from showering is 1.8 μg/m^3 accounting for 1.1% exposure and that the average human exposure concentration of 1.7 μg/m^3 from bathroom use after showering and from usage of the main house accounts for 0.35 and 99% exposure, respectively (ATSDR 2023).

Table 5-9. Reasonable Maximum Exposure Daily Inhalation Dose in µg/kg/day and Administered Dermal Dose of Chloroethane for the Target Person

Exposure group	Inhalation	Dermal
Birth–<1 year	1.2	6.2×10^{-6}
1–<2 years	1.3	5.7×10^{-6}
2–<6 years	1.0	4.9×10^{-6}
6–<11 years	0.66	4.0×10^{-6}
11–<16 years	0.47	3.2×10^{-6}
16–<21 years	0.40	3.0×10^{-6}
Adults	0.33	2.9×10^{-6}
Pregnant and breastfeeding women	0.53	2.9×10^{-6}

Source: ATSDR 2023

A study investigated the potential correlations and associations of vinyl chloride concentrations and detections in household water from wells and springs in Ohio and near (<10 km) previously active UOG wells (Clark et al. 2022). There was no correlation (rho=0.04, p>0.05) with vinyl chloride concentration and distance to the nearest UOG well in Ohio (Clark et al. 2022). The median concentration of 0.003 µg vinyl chloride/L was reported in 57% of the wells or springs that supplied water to 161 Ohio homes (Clark et al. 2022). However, Clark et al. (2022) did not find associations in odds ratios for detecting vinyl chloride with distance in either Pennsylvania (0.71, 95% confidence interval [CI]: 0.33, 1.53) or Ohio (1.08, 95% CI 0.85, 1.37) homes.

Inhalation of ambient or workplace air containing vinyl chloride is the most likely route of exposure for the general population. Typical values for the average daily intake of vinyl chloride by inhalation in urban/suburban and rural/remote areas not near emission sources are very small, since only trace levels of vinyl chloride are usually found in ambient air. While industry emissions of vinyl chloride have generally decreased (Ernes and Griffin 1996; TRI21 2023b), workers involved in the production or use of vinyl chloride are likely to be exposed to levels of vinyl chloride greater than the levels that the general public may be exposed to (TRI21 2023b).

Individuals located near or downwind of production facilities, hazardous waste disposal sites, and landfills may be exposed to atmospheric levels of vinyl chloride higher than ambient background levels. Concentrations around <5–30.7 µg/m^3 (<0.002–0.012 ppm) were measured in the air above some landfills (Baker and MacKay 1985; Stephens et al. 1986). Homes near one hazardous waste site in southern California were found to contain levels as high as 1,040 µg/m^3 (0.4 ppm) of vinyl chloride (Stephens et al.

1986) and homes near another site contained levels between 2.6 and 23.4 μg/m^3 (0.001–0.009 ppm) (Miller and Beizer 1985). These concentrations are several times greater than ambient air levels that are generally <0.02 μg/m^3 (McCarthy et al. 2006).

Cigarette smoke and smoke from small cigars have been found to contain vinyl chloride at levels of 5.6–27 ng per cigarette (Hoffmann et al. 1976) and as high as 34.8 ng per cigarette from conventional cigarettes utilizing human puffing behavior (Zenzen et al. 2012). Therefore, people who smoke may be potentially exposed to higher levels of vinyl chloride than nonsmokers.

Children are likely to be exposed to vinyl chloride via the same pathways that affect non-occupationally exposed adults; namely inhalation of ambient air and ingestion of food items or drinking water that may contain low levels of vinyl chloride. According to the information from Chemical Data Reporting (CDR) for 2020, there are no reported consumer or commercial uses of vinyl chloride in products intended for children from reporting facilities in the United States; data for 2012 and 2016 include one facility in the United States where the use intended for children's products is unknown or not reasonably ascertainable (ChemView 2023; EPA 2021). No body burden studies that quantitatively or qualitatively identified vinyl chloride in children were located.

5.7 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

In the past, airborne levels of vinyl chloride in occupational settings were often >200 ppmv; however, beginning in 1974, Occupational Safety and Health Administration (OSHA) regulations resulted in increased engineering controls in the PVC manufacturing process, which have reduced airborne levels to 1–2 ppmv (Borrelli et al. 2005).

Workers who are involved in welding applications that use PVC pipes or other PVC materials may potentially be exposed to higher levels of vinyl chloride than the general population. Welding PVC containing material produces fumes that may contain vinyl chloride; however, exposure is expected to be limited and minimized by process control methods and good practice. In an older PVC thermal welding study that varied welding temperature and environmental conditions, vinyl chloride levels in air were below the detection limit (0.05–0.2 ppm [0.13–0.51 mg/m^3]) (Williamson and Kavanagh 1987). The highest levels were observed under normal welding with reduced ventilation (0.2 ppm) and during severe heating without ventilation (<0.5–0.1ppm). Ernes and Griffin (1996) evaluated VOC emissions from

PVC extrusion processes using a resin mixture continuously fed into the extruder under normal operating conditions. The study authors found no evidence of vinyl chloride.

The exposure concentration of vinyl chloride for employees working near flowback pits in the Marcellus Shale natural gas drilling sites was determined to be 0.028–2.8 $\mu g/m^3$ (0.011–1.096 ppb) (Bloomdahl et al. 2014).

In the United States, vinyl chloride is an OSHA regulated substance. Current OSHA regulations impose a permissible exposure limit (PEL) of 1 ppm (2.6 mg/m^3) averaged over an 8-hour period or a short-term exposure of no more than 5 ppm over a 15-minute period (Cowfer and Gorensek 2006). Where concentrations cannot be lowered below the PEL of 1 ppm, employers must create an area with controlled access and a respirator program conforming to OSHA standards.