

1 **2. EXPOSURE CHARACTERIZATION**

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4 The purpose of this exposure characterization is to summarize information about

5 trichloroethylene (TCE) sources, releases, media levels, and exposure pathways for the general

6 population (occupational exposure is also discussed to a lesser extent). It is not meant as a

7 substitute for a detailed exposure assessment for a particular risk assessment application. While

8 this section primarily addresses TCE, it also includes some information on a number of related

9 compounds. These related compounds include metabolites of TCE and other parent compounds

10 that produce similar metabolites as shown in Table 2-1. The first column in this table lists the

11 principal TCE metabolites in humans (trichloroethanol, trichloroethanol-glucuronide and

12 trichloroacetic acid) as well as a number of minor ones (Agency for Toxic Substances and

13 Disease Registry [ATSDR], 1997a). The subsequent columns list parent compounds that can

14 produce some of the same metabolites. The metabolic reaction pathways are much more

15 complicated than implied here and it should be understood that this table is intended only to

16 provide a general understanding of which parent compounds lead to which TCE metabolites.

17 Exposure to the TCE-related compounds can alter or enhance TCE’s metabolism and toxicity by

18 generating higher internal metabolite concentrations than would result from TCE exposure by

19 itself. This characterization is based largely on earlier work by Wu and Schaum (2000, 2001),

20 but also provides updates in a number of areas.

21

22 **Table 2-1. TCE metabolites and related parent compounds\***

23

TCE metabolites	Parent compounds				
	Tetrachloro-ethylene	1,1-Dichloro-ethane	1,1,1-Tri-chloroethane	1,1,1,2-Tetra-chloroethane	1,2-Dichloro-ethylene
Oxalic acid				X	X
Chloral	X				
Chloral hydrate	X				
Monochloroacetic acid	X	X	X	X	X
Dichloroacetic acid	X	X		X	
Trichloroacetic acid	X		X	X	
Trichloroethanol	X		X	X	
Trichloroethanol-glucuronide	X		X	X	

24 \* X indicates that the parent compound can produce the corresponding metabolite (Hazardous Substances Data

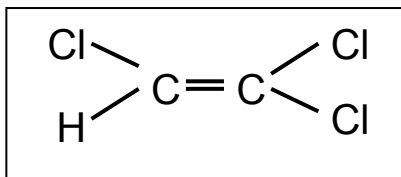
25 Bank, <http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB>).

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1 **2.1. ENVIRONMENTAL SOURCES**

2 TCE is a stable, colorless liquid with a chloroform-like odor and chemical formula  
3  $C_2Cl_3H$  as diagrammed in Figure 2-1 (Lewis, 2001). Its chemical properties are listed in  
4 Table 2-2.  
5



7 **Figure 2-1. Molecular structure of TCE.**

8  
9  
10 **Table 2-2. Chemical properties of TCE**

11

Property	Value	Reference
Molecular weight	131.39	Lide, 1998
Boiling point	87.2°C	Lide, 1998
Melting point	-84.7°C	Lide, 1998
Density	1.4642 at 20°C	Merck Index, 1996
Solubility	1,280 mg/L water at 25°C	Hotvath et al., 1999
Vapor pressure	69.8 mmHG @ 25°C	Boublik et al., 1984
Vapor density	4.53 (air = 1)	Merck Index, 1996
Henry's Law Constant	$9.85 \times 10^{-3}$ atm-cu m/mol @ 25°C	Leighton, 1981
Octanol/water partition coefficient	$\log K_{ow} = 2.61$	Hansch, 1995
Air concentration conversion	1 ppb = $5.38 \mu\text{g}/\text{m}^3$	HSDB, 2002

12  
13  
14 Trichloroethylene has been produced commercially since the 1920s in many countries by  
15 chlorination of ethylene or acetylene. Its use in vapor degreasing began in the 1920s. In the  
16 1930s, it was introduced for use in dry cleaning. This use was largely discontinued in the 1950s  
17 and was replaced with tetrachloroethylene (ATSDR, 1997a). More recently, 80–90% of  
18 trichloroethylene production worldwide is used for degreasing metals (International Agency for  
19 Research on Cancer [IARC], 1995). It is also used in adhesives, paint-stripping formulations,  
20 paints, lacquers, and varnishes (SRI, 1992). A number of past uses in cosmetics, drugs, foods,  
21 and pesticides have now been discontinued including use as an extractant for spice oleoresins,

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1 natural fats and oils, hops and decaffeination of coffee (IARC, 1995), and as a carrier solvent for  
 2 the active ingredients of insecticides and fungicides, and for spotting fluids (WHO, 1985;  
 3 ATSDR, 1997a). The production of TCE in the United States peaked in 1970 at 280 million kg  
 4 (616 million pounds) and declined to 60 million kg (132 million pounds) in 1998 (United States  
 5 Geological Survey [USGS], 2006). In 1996, the United States imported 4.5 million kg  
 6 (10 million pounds) and exported 29.5 million kg (65 million pounds) (Chemical Marketing  
 7 Reporter, 1997). Table 2-3 summarizes the basic properties and principal uses of the TCE  
 8 related compounds.

9  
 10 **Table 2-3. Properties and uses of TCE related compounds**

	<b>Water solubility (mg/L)</b>	<b>Vapor pressure (mmHG)</b>	<b>Uses</b>	<b>Sources</b>
Tetrachloroethylene	150	18.5 @25°C	Dry cleaning, degreasing, solvent	a
1,1,1-Trichloroethane	4,400	124 @25°C	Solvents, degreasing	a
1,2-Dichloroethylene	3,000–6,000	273–395 @30°C	Solvents, chemical intermediates	a
1,1,1,2-Tetrachloroethane	1,100	14 @25°C	Solvents, but currently not produced in United States	a,b
1,1-Dichloroethane	5,500	234 @25°C	Solvents, chemical intermediates	a
Chloral	High	35 @20°C	Herbicide production	a
Chloral hydrate	High	NA	Pharmaceutical production	a
Monochloroacetic acid	High	1 @43°C	Pharmaceutical production	a
Dichloroacetic acid	High	<1 @20°C	Pharmaceuticals, not widely used	a
Trichloroacetic acid	High	1 @50°C	Herbicide production	a
Oxalic acid	220,000	0.54 @105°C	Scouring/cleaning agent, degreasing	b
Dichlorovinyl cysteine	Not available	Not available	Not available	
Trichloroethanol	Low	NA	Anesthetics and chemical intermediate	c

12  
 13 <sup>a</sup>Wu and Schaum (2001).

14 <sup>b</sup>HSDB (2003).

15 <sup>c</sup>Lewis (2001).

1 Releases of TCE from nonanthropogenic activities are negligible (HSDB, 2002). Most of  
 2 the TCE used in the United States is released to the atmosphere, primarily from vapor degreasing  
 3 operations (ATSDR, 1997a). Releases to air also occur at treatment and disposal facilities, water  
 4 treatment facilities, and landfills (ATSDR, 1997a). TCE has also been detected in stack  
 5 emissions from municipal and hazardous waste incineration (ATSDR, 1997a). TCE is on the list  
 6 for reporting to U.S. Environmental Protection Agency (U.S. EPA)'s Toxics Release Inventory  
 7 (TRI). Reported releases into air predominate over other types and have declined over the period  
 8 1994 to 2004 (see Table 2-4).

9  
 10 **Table 2-4. Toxics Release Inventory (TRI) releases of TCE (pounds/year)**

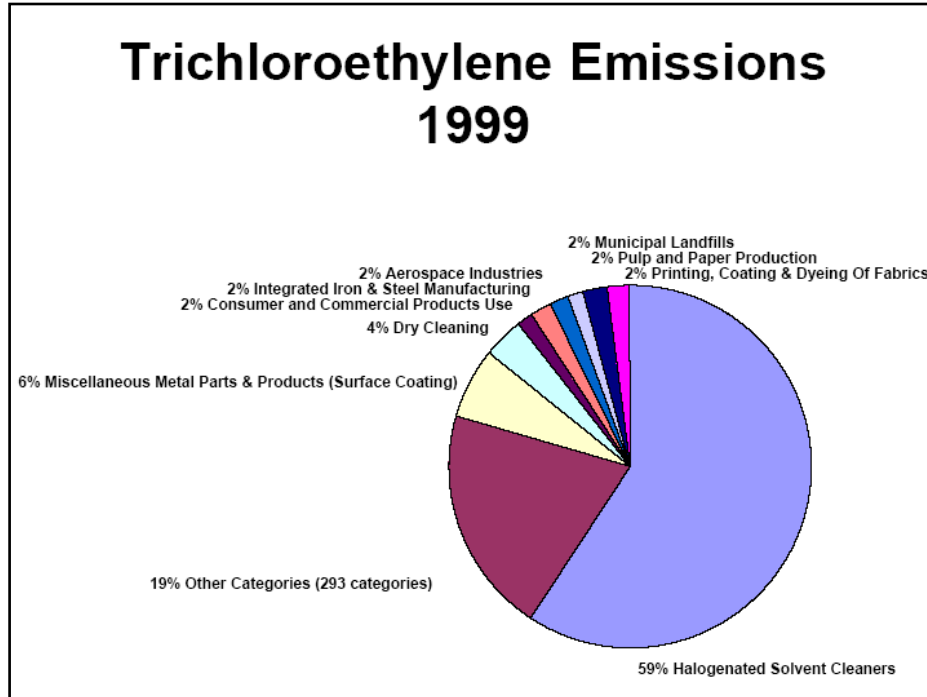
Year	On-site fugitive air	On-site stack air	Total on-site air emissions	On-site surface water discharges	Total on-site underground injection	Total on-site releases to land	Total off-site disposal or other releases	Total on- and off-site disposal or other releases
1994	15,018,818	15,929,943	30,948,761	1,671	288	4,070	96,312	31,051,102
1995	12,498,086	13,784,853	26,282,939	1,477	550	3,577	74,145	26,362,688
1996	10,891,223	10,995,228	21,886,451	541	1,291	9,740	89,527	21,987,550
1997	9,276,150	8,947,909	18,224,059	568	986	3,975	182,423	18,412,011
1998	6,769,810	6,504,289	13,274,099	882	593	800	136,766	13,413,140
1999	5,861,635	4,784,057	10,645,692	1,034	0	148,867	192,385	10,987,978
2000	5,485,493	4,375,516	9,861,009	593	47,877	9,607	171,952	10,091,038
2001	4,968,282	3,453,451	8,421,733	406	98,220	12,609	133,531	8,666,499
2002	4,761,104	3,436,289	8,197,393	579	140,190	230	139,398	8,477,790
2003	3,963,054	3,121,718	7,084,772	595	90,971	150,642	66,894	7,393,873
2004	3,040,460	3,144,980	6,185,440	216	123,637	2	71,780	6,381,075
2005	2,733,983	2,893,168	5,627,152	533	86,817	4,711	60,074	5,779,287
2006	2,816,241	2,795,184	5,611,425	482	0	77,339	90,758	5,780,004

12  
 13 Source: U.S. EPA TRI Explorer, <http://www.epa.gov/triexplorer/trends.htm>.

14  
 15  
 16 Under the National-Scale Air Toxics Assessment (NSATA) program, U.S. EPA has  
 17 developed an emissions inventory for TCE (U.S. EPA, 2007a). The inventory includes sources  
 18 in the United States plus the Commonwealth of Puerto Rico and the U.S. Virgin Islands. The  
 19 types of emission sources in the inventory include large facilities, such as waste incinerators and  
 20 factories and smaller sources, such as dry cleaners and small manufacturers. Figures 2-2 and 2-3

1 show the results of the 1999 emissions inventory for TCE. Figure 2-2 shows the percent  
2 contribution to total emissions by source category. A variety of sources have TCE emissions  
3 with the largest ones identified as halogenated solvent cleaners and metal parts and products.  
4 Figure 2-3 shows a national map of the emission density (tons/sq mi-yr) for TCE. This map  
5 shows the highest densities in the far west and northeastern regions of the United States.  
6 Emissions range from 0 to 4.12 tons/mi<sup>2</sup>-yr.

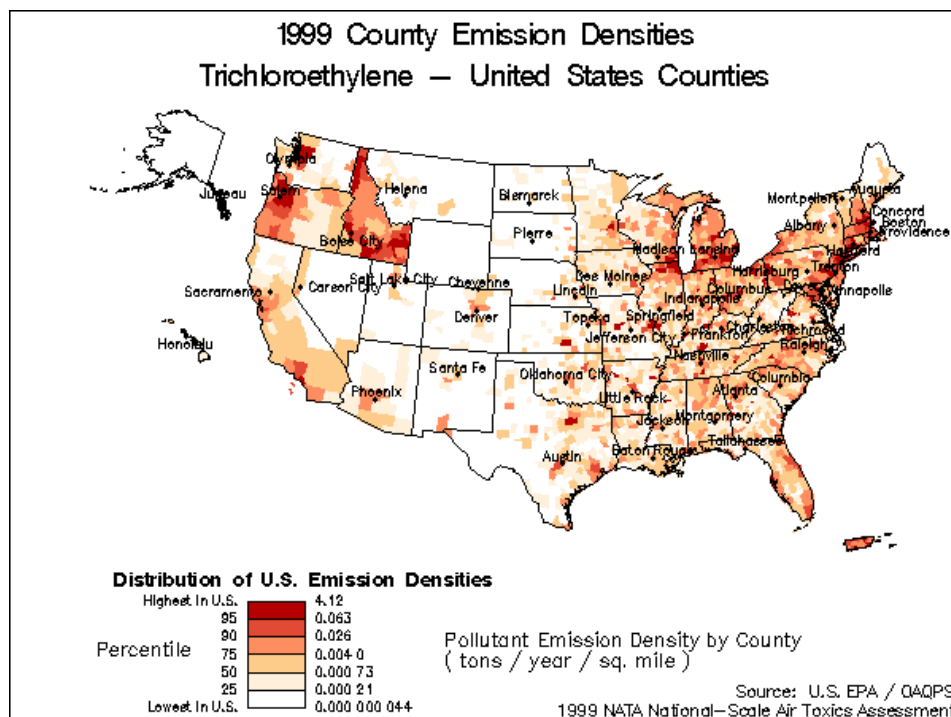
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**Figure 2-2. Source contribution to TCE emissions.**



2

3 **Figure 2-3. Annual emissions of TCE.**

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## 6 **2.2. ENVIRONMENTAL FATE**

### 7 **2.2.1. Fate in Terrestrial Environments**

8 The dominant fate of trichloroethylene released to surface soils is volatilization. Because  
9 of its moderate water solubility, trichloroethylene introduced into soil (e.g., landfills) also has the  
10 potential to migrate through the soil into groundwater. The relatively frequent detection of  
11 trichloroethylene in groundwater confirms this. Biodegradation in soil and groundwater may  
12 occur at a relatively slow rate (half-lives on the order of months to years) (Howard et al., 1991).

13

### 14 **2.2.2. Fate in the Atmosphere**

15 In the atmosphere, trichloroethylene is expected to be present primarily in the vapor  
16 phase, rather than sorbed to particulate, because of its high vapor pressure. Some removal by  
17 scavenging during wet precipitation is expected because of its moderate water solubility. The  
18 major degradation process affecting vapor phase trichloroethylene is photo-oxidation by  
19 hydroxyl radicals. Photolysis in the atmosphere proceeds very slowly, if at all.  
20 Trichloroethylene does not absorb ultraviolet light at wavelengths of less than 290 nm and thus  
21 will not directly photolyze. Based on measured rate data for the vapor phase photo-oxidation

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1 reaction with hydroxyl radicals, the estimated half-life of trichloroethylene in the atmosphere is  
2 on the order of 1 to 11 days with production of phosgene, dichloroacetyl chloride, and formyl  
3 chloride. Under smog conditions, degradation is more rapid (half-life on the order of hours)  
4 (HSDB, 2002; Howard et al., 1991).

### 6 **2.2.3. Fate in Aquatic Environments**

7 The dominant fate of trichloroethylene released to surface waters is volatilization  
8 (predicted half-life of minutes to hours). Bioconcentration, biodegradation, and sorption to  
9 sediments and suspended solids are not thought to be significant (HSDB, 2002).

10 Trichloroethylene is not hydrolyzed under normal environmental conditions. However, slow  
11 photo-oxidation in water (half-life of 10.7 months) has been reported (HSDB, 2002; Howard et  
12 al., 1991).

## 13 **2.3. EXPOSURE CONCENTRATIONS**

14 TCE levels in the various environmental media result from the releases and fate processes  
15 discussed in Sections 2.1 and 2.2. No statistically based national sampling programs have been  
16 conducted that would allow estimates of true national means for any environmental medium. A  
17 substantial amount of air and groundwater data, however, has been collected as well as some  
18 data in other media, as described below.

### 20 **2.3.1. Outdoor Air—Measured Levels**

21 TCE has been detected in the air throughout the United States. According to ATSDR  
22 (1997a), atmospheric levels are highest in areas concentrated with industry and population, and  
23 lower in remote and rural regions. Table 2-5 shows levels of TCE measured in the ambient air at  
24 a variety of locations in the United States.

1  
2

**Table 2-5. Concentrations of trichloroethylene in ambient air**

Area	Year	Concentration ( $\mu\text{g}/\text{m}^3$ )	
		Mean	Range
<b><i>Rural</i></b>			
Whiteface Mountain, NY <sup>a</sup>	1974	0.5	<0.3–1.9
Badger Pass, CA <sup>a</sup>	1977	0.06	0.005–0.09
Reese River, NV <sup>a</sup>	1977	0.06	0.005–0.09
Jetmar, KS <sup>a</sup>	1978	0.07	0.04–0.11
All rural sites	1974–1978		0.005–1.9
<b><i>Urban and Suburban</i></b>			
New Jersey <sup>a</sup>	1973–79	9.1	ND–97
New York City, NY <sup>a</sup>	1974	3.8	0.6–5.9
Los Angeles, CA <sup>a</sup>	1976	1.7	0.14–9.5
Lake Charles, LA <sup>a</sup>	1976–78	8.6	0.4–11.3
Phoenix, AZ <sup>a</sup>	1979	2.6	0.06–16.7
Denver, CO <sup>a</sup>	1980	1.07	0.15–2.2
St. Louis, MO <sup>a</sup>	1980	0.6	0.1–1.3
Portland, OR <sup>a</sup>	1984	1.5	0.6–3.9
Philadelphia, PA <sup>a</sup>	1983–1984	1.9	1.6–2.1
Southeast Chicago, IL <sup>b</sup>	1986–1990	1.0	
East St. Louis, IL <sup>b</sup>	1986–1990	2.1	
District of Columbia <sup>c</sup>	1990–1991	1.94	1–16.65
Urban Chicago, IL <sup>d</sup>	pre–1993	0.82–1.16	
Suburban Chicago, IL <sup>d</sup>	pre–1993	0.52	
300 cities in 42 states <sup>e</sup>	pre–1986	2.65	
Several Canadian Cities <sup>f</sup>	1990	0.28	
Several United States Cities <sup>f</sup>	1990	6.0	
Phoenix, AZ <sup>g</sup>	1994–1996	0.29	0–1.53
Tucson, AZ <sup>g</sup>	1994–1996	0.23	0–1.47
All urban/suburban sites	1973–1996		0–97

3  
4 <sup>a</sup>IARC (1995).  
5 <sup>b</sup>Sweet (1992).  
6 <sup>c</sup>Hendler (1992).  
7 <sup>d</sup>Scheff (1993).  
8 <sup>e</sup>Shah (1988).  
9 <sup>f</sup>Bunce (1994).  
10 <sup>g</sup>Zielinska (1998).

11  
12

13 More recent ambient air measurement data for TCE were obtained from U.S. EPA’s Air  
14 Quality System database at the AirData Web site: <http://www.epa.gov/air/data/index.html> (U.S.  
15 EPA, 2007b). These data were collected from a variety of sources including state and local  
16 environmental agencies. The data are not from a statistically based survey and cannot be



1 assumed to provide nationally representative values. The most recent data (2006) come from  
 2 258 monitors located in 37 states. The means for these monitors range from 0.03 to 7.73  $\mu\text{g}/\text{m}^3$   
 3 and have an overall average of 0.23  $\mu\text{g}/\text{m}^3$ . Table 2-6 summarizes the data for the years  
 4 1999–2006. The data suggest that levels have remained fairly constant since 1999 at about  
 5 0.3  $\mu\text{g}/\text{m}^3$ . Table 2-7 shows the monitoring data organized by land setting (rural, suburban, or  
 6 urban) and land use (agricultural, commercial, forest, industrial, mobile, and residential). Urban  
 7 air levels are almost 4 times higher than rural areas. Among the land use categories, TCE levels  
 8 are highest in commercial/industrial areas and lowest in forest areas.

9  
 10 **Table 2-6. TCE ambient air monitoring data ( $\mu\text{g}/\text{m}^3$ )**  
 11

Year	Number of monitors	Number of states	Mean	Standard deviation	Median	Range
1999	162	20	0.30	0.53	0.16	0.01–4.38
2000	187	28	0.34	0.75	0.16	0.01–7.39
2001	204	31	0.25	0.92	0.13	0.01–12.90
2002	259	41	0.37	1.26	0.13	0.01–18.44
2003	248	41	0.35	0.64	0.16	0.02–6.92
2004	256	37	0.32	0.75	0.13	0.00–5.78
2005	313	38	0.43	1.05	0.14	0.00–6.64
2006	258	37	0.23	0.55	0.13	0.03–7.73

12 Source: U.S. EPA’s Air Quality System database at the AirData Web site: <http://www.epa.gov/air/data/index.html>.  
 13  
 14  
 15

16 **Table 2-7. Mean TCE air levels across monitors by land setting and use**  
 17 **(1985 to 1998)**  
 18

	Rural	Suburban	Urban	Agricultural	Commercial	Forest	Industrial	Mobile	Residential
Mean concentration ( $\mu\text{g}/\text{m}^3$ )	0.42	1.26	1.61	1.08	1.84	0.1	1.54	1.5	0.89
<i>n</i>	93	500	558	31	430	17	186	39	450

19 Source: U.S. EPA’s Air Quality System database at the AirData Web site: <http://www.epa.gov/air/data/index.html>.  
 20  
 21  
 22  
 23

### 2.3.2. Outdoor Air—Modeled Levels

Under the National-Scale Air Toxics Assessment program, U.S. EPA has compiled emissions data and modeled air concentrations/exposures for the Criteria Pollutants and Hazardous Air Pollutants (U.S. EPA, 2007a). The results of the 1999 emissions inventory for TCE were discussed earlier and results presented in Figures 2-2 and 2-3. A computer simulation model known as the Assessment System for Population Exposure Nationwide (ASPEN) is used to estimate toxic air pollutant concentrations (U.S. EPA, 2005). This model is based on the U.S. EPA's Industrial Source Complex Long Term model which simulates the behavior of the pollutants after they are emitted into the atmosphere. ASPEN uses estimates of toxic air pollutant emissions and meteorological data from National Weather Service Stations to estimate air toxics concentrations nationwide. The ASPEN model takes into account important determinants of pollutant concentrations, such as

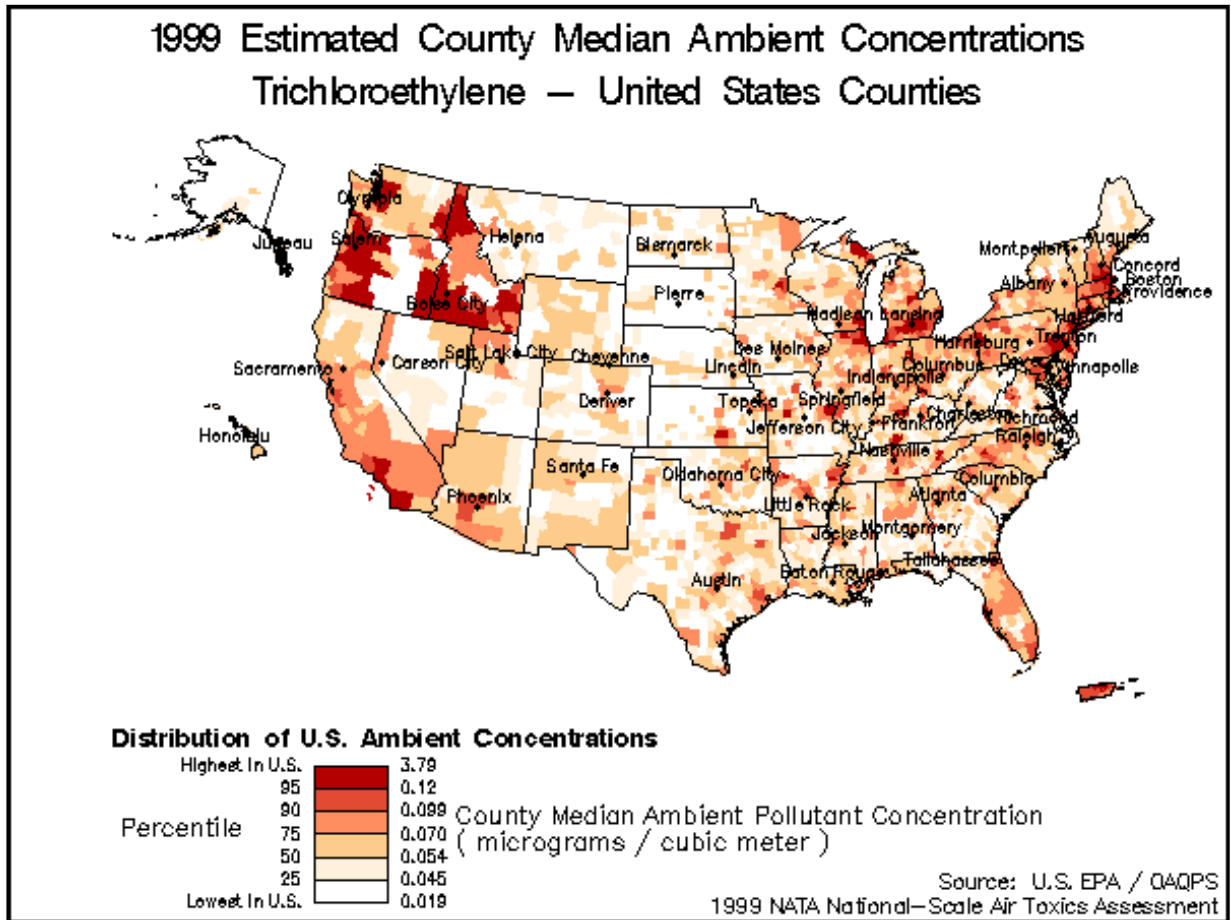
- rate of release;
- location of release;
- the height from which the pollutants are released;
- wind speeds and directions from the meteorological stations nearest to the release;
- breakdown of the pollutants in the atmosphere after being released (i.e., reactive decay);
- settling of pollutants out of the atmosphere (i.e., deposition) and
- transformation of one pollutant into another (i.e., secondary formation).

The model estimates toxic air pollutant concentrations for every census tract in the continental United States, the Commonwealth of Puerto Rico and the U.S. Virgin Islands. Census tracts are land areas defined by the U.S. Bureau of the Census and typically contain about 4,000 residents each. Census tracts are usually smaller than 2 square miles in size in cities but much larger in rural areas.

Figure 2-4 shows the results of the 1999 ambient air concentration modeling for TCE. The county median air levels range from 0 to 3.79  $\mu\text{g}/\text{m}^3$  and an overall median of 0.054  $\mu\text{g}/\text{m}^3$ . They have a pattern similar to the emission densities shown in Figure 2-3. These NSATA modeled levels appear lower than the monitoring results presented above. For example, the 1999 air monitoring data (Table 2-6) indicates a median outdoor air level of 0.16  $\mu\text{g}/\text{m}^3$  which is about 3 times as high as the modeled 1999 county median (0.054  $\mu\text{g}/\text{m}^3$ ). However, it should be understood that the results from these two efforts are not perfectly comparable. The modeled value is a median of county levels for the entire United States which includes many rural areas. The monitors cover many fewer areas ( $n = 162$  for 1999) and most are in nonrural locations. A better analysis is provided by U.S. EPA (2007) which presents a comparison of modeling results

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1 from NSATA to measured values at the same locations. For 1999, it was found that  
 2 formaldehyde levels were underestimated at 79% of the sites ( $n = 92$ ). Thus, while the NSATA  
 3 modeling results are useful for understanding geographic distributions, they may frequently  
 4 underestimate ambient levels.



6  
7 **Figure 2-4. Modeled ambient air concentrations of TCE.**

8  
9  
10 **2.3.3. Indoor Air**

11 TCE can be released to indoor air from use of consumer products that contain it (i.e.,  
 12 adhesives and tapes), vapor intrusion (migration of volatile chemicals from the subsurface into  
 13 overlying buildings) and volatilization from the water supply. Where such sources are present, it  
 14 is likely that indoor levels will be higher than outdoor levels. A number of studies have  
 15 measured indoor levels of TCE:

- 16
- 17 • The 1987 U.S. EPA Total Exposure Assessment Methodology study (U.S. EPA, 1987)  
 18 showed that the ratio of indoor to outdoor TCE concentrations for residences in  
 19 Greensboro, NC, was about 5:1.

- 1 • In two homes using well water with TCE levels averaging 22 to 128 µg/L, the TCE levels  
2 in bathroom air ranged from <500 to 40,000 µg/m<sup>3</sup> when the shower ran less than 30  
3 minutes (Andelman et al., 1985).
- 4 • Shah and Singh (1988) report an average indoor level of 7.2 µg/m<sup>3</sup> based on over 2,000  
5 measurements made in residences and workplaces during 1981–1984 from various  
6 locations across the United States.
- 7 • Hers et al. (2001) provides a summary of indoor air TCE measurements at locations in  
8 United States, Canada, and Europe with a range of <1 to 165 µg/m<sup>3</sup>.
- 9 • Sapkota et al. (2005) measured TCE levels inside and outside of the Baltimore Harbor  
10 Tunnel toll booths during the summer of 2001. Mean TCE levels were 3.11 µg/m<sup>3</sup>  
11 indoors and 0.08 µg/m<sup>3</sup> outdoors based on measurements on 7 days. The authors  
12 speculated that indoor sources, possibly dry cleaning residues on uniforms, were the  
13 primary source of the indoor TCE.
- 14 • Sexton et al. (2005) measured TCE levels inside and outside residences in  
15 Minneapolis/St. Paul metropolitan area. Two day samples were collected over three  
16 seasons in 1999. Mean TCE levels were 0.5 µg/m<sup>3</sup> indoors (*n* = 292), 0.2 µg/m<sup>3</sup> outdoors  
17 (*n* = 132) and 1.0 µg/m<sup>3</sup> based on personal sampling (*n* = 288).
- 18 • Zhu et al. (2005) measured TCE levels inside and outside of residences in Ottawa,  
19 Canada. 75 homes were randomly selected and measurements were made during the  
20 winter of 2002/2003. TCE was above detection limits in the indoor air of 33% of the  
21 residences and in the outdoor air of 19% of the residences. The mean levels were  
22 0.06 µg/m<sup>3</sup> indoors and 0.08 µg/m<sup>3</sup> outdoors. Given the high frequency of nondetects, a  
23 more meaningful comparison can be made on basis of the 75<sup>th</sup> percentiles: 0.08 µg/m<sup>3</sup>  
24 indoors and 0.01 µg/m<sup>3</sup> outdoors.

25  
26 TCE levels measured indoors have been directly linked to vapor intrusion at two sites in New  
27 York:

- 28  
29 • TCE vapor intrusion has occurred in buildings/residences near a former Smith Corona  
30 manufacturing facility located in Cortlandville, NY. An extensive sampling program  
31 conducted in 2006 has detected TCE in groundwater (1–13 µg/L), soil gas (6–97 µg/m<sup>3</sup>),  
32 subslab gas (2–1,600 µg/m<sup>3</sup>), and indoor air (1–17 µg/m<sup>3</sup>) (NYSDEC, 2006a).
- 33 • Evidence of vapor intrusion of TCE has also been reported in buildings and residences in  
34 Endicott, NY. Sampling in 2003 showed total volatile organic compounds (VOCs) in  
35 soil gas exceeding 10,000 µg/m<sup>3</sup> in some areas. Indoor air sampling detected TCE levels  
36 ranging from 1 to 140 µg/m<sup>3</sup> (NYSDEC, 2006b).

37  
38 Little et al. (1992) developed attenuation coefficients relating contaminants in soil gas  
39 (assumed to be in chemical equilibrium with the groundwater) to possible indoor levels as a  
40 result of vapor intrusion. On this basis they estimated that TCE groundwater levels of 540 µg/L,

1 (a high contamination level) could produce indoor air levels of 5 to 500 µg/m<sup>3</sup>. Vapor intrusion  
 2 is likely to be a significant source only in situations where residences are located near soils or  
 3 groundwater with high contamination levels. U.S. EPA (2002) recommends considering vapor  
 4 intrusion when volatiles are suspected to be present in groundwater or soil at a depth of  
 5 <100 feet. Hers et al. (2001) concluded that the contribution of VOCs from subsurface sources  
 6 relative to indoor sources is small for most chemicals and sites.

7

8 **2.3.4. Water**

9 A number of early (pre-1990) studies measured TCE levels in natural water bodies  
 10 (levels in drinking water are discussed later in this section) as summarized in Table 2-8.  
 11 According to IARC (1995), the reported median concentrations of TCE in 1983–1984 were  
 12 0.5 µg/L in industrial effluents and 0.1 µg/L in ambient water. Results from an analysis of the  
 13 U.S. EPA STORET Data Base (1980–1982) showed that TCE was detected in 28% of 9,295  
 14 surface water reporting stations nationwide (ATSDR, 1997a). A more recent search of the  
 15 STORET database for TCE measurements nationwide during 2008 in streams, rivers and lakes  
 16 indicated 3 detects (0.03 to 0.04 µg/L) out of 150 samples (STORET Database,  
 17 <http://www.epa.gov/storet/dbtop.html>).

18

19 **Table 2-8. Concentrations of trichloroethylene in water based on pre-1990**  
 20 **studies**

21

Water type	Location	Year	Mean (µg/L)	Median (µg/L)	Range (µg/L)	Number of samples	Ref.
Industrial effluent	U.S.	83		0.5		NR	IARC, 1995
Surface waters	U.S.	83		0.1		NR	IARC, 1995
Rainwater	Portland, OR	84	0.006		0.002–0.02	NR	Ligocki et al., 1985
Groundwater	MN	83			0.2–144	NR	Sabel et al, 1984
	NJ	76			≤1,530	NR	Burmester et al., 1982
	NY	80			≤3,800	NR	Burmester et al., 1982
	PA	80			≤27,300	NR	Burmester et al., 1982
	MA	76			≤900	NR	Burmester et al., 1982
	AZ				8.9–29	NR	IARC, 1995
Drinking water	U.S.	76			0.2–49		IARC, 1995
	U.S	77			0–53		IARC, 1995
	U.S.	78			0.5–210		IARC, 1995
	MA	84			max. 267		IARC, 1995
	NJ	84	23.4		max. 67	1130	Cohn et al., 1994
	CA	85			8-12	486	U.S. EPA, 1987
	CA	84	66			486	U.S. EPA, 1987
	NC	84	5			48	U.S. EPA, 1987
ND	84	5			48	U.S. EPA, 1987	

22 NR = Not Reported.

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1 ATSDR (1997a) has reported that TCE is the most frequently reported organic  
2 contaminant in groundwater and the one present in the highest concentration in a summary of  
3 ground water analyses reported in 1982. It has been estimated that between 9 and 34% of the  
4 drinking water supply sources tested in the United States may have some trichloroethylene  
5 contamination. This estimate is based on available Federal and State surveys (ATSDR, 1997a).

6 Squillace et al. (2004) reported TCE levels in shallow groundwater based on data from  
7 the National Water Quality Assessment Program managed by USGS. Samples from 518 wells  
8 were collected from 1996 to 2002. All wells were located in residential or commercial areas and  
9 had a median depth of 10 m. The authors reported that approximately 8.3% of the well levels  
10 were above the detection limit (level not specified), 2.3% were above 0.1 µg/L and 1.7% were  
11 above 0.2 µg/L.

12 As part of the Agency's first Six-Year Review, EPA obtained analytical results for over  
13 200,000 monitoring samples reported at 23,035 public water systems in 16 states (U.S. EPA,  
14 2003). Approximately 2.6% of the systems had at least one sample exceed a minimum reporting  
15 level of 0.5 µg/L; almost 0.65% had at least one sample that exceeds the MCL of 5 µg/L. Based  
16 on average system concentrations estimated by U.S. EPA, 54 systems (0.23%) had an average  
17 concentration that exceeded the MCL. U.S. EPA's statistical analysis to extrapolate the sample  
18 result to all systems regulated for TCE resulted in an estimate of 154 systems with average TCE  
19 concentrations that exceed the MCL.

20 TCE concentrations in ground water have been measured extensively in California. The  
21 data were derived from a survey of water utilities with more than 200 service connections. The  
22 survey was conducted by the California Department of Health Services (CA DHS, 1986). From  
23 January 1984 through December 1985, untreated water from wells in 819 water systems were  
24 sampled for organic chemical contamination. The water systems use a total of 5,550 wells,  
25 2,947 of which were sampled. TCE was found in 187 wells at concentrations up to 440 µg/L,  
26 with a median concentration among the detects of 3.0 µg/L. Generally, the wells with the highest  
27 concentrations were found in the heavily urbanized areas of the state. Los Angeles County  
28 registered the greatest number of contaminated wells (149).

29 A second California study collected data on TCE levels in public drinking water  
30 (Williams et al., 2002). The data were obtained from the CA DHS. The data spanned the years  
31 1995 to 2001 and the number of samples for each year ranged from 3,447 to 4,226. The percent  
32 of sources that were above the detection limit ranged from 9.6 to 11.7 per year (detection limits  
33 not specified). The annual average detected concentrations ranged from 14.2 to 21.6 µg/L.  
34 Although not reported, the overall average concentration of the samples (assuming an average of  
35 20 µg/L among the samples above the detection limit, 10% detection rate and 0 for the  
36 nondetects) would be about 2 µg/L.

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1 The USGS (2006) conducted a national assessment of 55 VOCs, including  
2 trichloroethylene, in ground water. A total of 3,500 water samples were collected during  
3 1985–2001. Samples were collected at the well head prior to any form of treatment. The types  
4 of wells sampled included 2,400 domestic wells and 1,100 public wells. Almost 20% of the  
5 samples contained one or more of the VOCs above the assessment level of 0.2 µg/L. The  
6 detection frequency increased to over 50% when a subset of samples was analyzed with a low  
7 level method that had an assessment level of 0.02 µg/L. The largest detection frequencies were  
8 observed in California, Nevada, Florida, the New England States and Mid-Atlantic states. The  
9 most frequently detected VOCs (>1% of samples) include TCE, tetrachloroethylene,  
10 1,1,1-trichloroethane (methyl chloroform), 1,2 dichloroethylene, and 1,1-dichloroethane.  
11 Findings specific to TCE include the following:

- 12 • Detection frequency was 2.6% at 0.2 µg/L and was 3.8% at 0.02 µg/L.
- 13 • The median concentration was 0.15 µg/L with a range of 0.02 to 100 µg/L.
- 14 • The number of samples exceeding the MCL (5 µg/L) was 6 at domestic wells and 9 at  
15 public wells.  
16

17  
18 USGS (2006) also reported that four solvents (TCE, tetrachloroethylene,  
19 1,1,1-trichloroethane and methylene chloride) occurred together in 5% of the samples. The most  
20 frequently occurring two-solvent mixture was TCE and tetrachloroethylene. The report stated  
21 that the most likely reason for this co-occurrence is the reductive dechlorination of  
22 tetrachloroethylene to TCE.  
23

### 24 **2.3.5. Other Media**

25 Levels of TCE were found in the sediment and marine animal tissue collected in  
26 1980–1981 near the discharge zone of a Los Angeles County waste treatment plant.  
27 Concentrations were 17 µg/L in the effluent, <0.5 µg/kg in dry weight in sediment, and  
28 0.3–7 µg/kg wet weight in various marine animal tissue (IARC, 1995). TCE has also been found  
29 in a variety of foods. FDA has limits on TCE use as a food additive in decaffeinated coffee and  
30 extract spice oleoresins (see Table 2-15). Table 2-9 summarizes data from two sources:  
31

- 32 • IARC (1995) reports average concentrations of TCE in limited food samples collected in  
33 the United States.
- 34 • Fleming-Jones and Smith (2003) measured VOC levels in over 70 foods collected from  
35 1996 to 2000 as part of the FDA’s Total Diet Program. All foods were collected directly  
36 from supermarkets. Analysis was done on foods in a ready-to-eat form. Sample sizes for  
37 most foods were in the 2–5 range.

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**Table 2-9. Levels in food**

<b>IARC (1995)</b>	<b>Fleming-Jones and Smith (2003)</b>
Cheese 3.8 µg/kg Butter and Margarine 73.6 µg/kg	Cheese 2–3 µg/kg Butter 7–9 µg/kg Margarine 2–21 µg/kg Cheese Pizza 2 µg/kg
Peanut Butter 0.5 µg/kg	Nuts 2–5 µg/kg Peanut Butter 4–70 µg/kg
	Ground Beef 3–6 µg/kg Beef Frankfurters 2–105 µg/kg Hamburger 5–9 µg/kg Cheeseburger 7 µg/kg Chicken Nuggets 2–5 µg/kg Bologna 2–20 µg/kg Pepperoni Pizza 2 µg/kg
	Banana 2 µg/kg Avocado 2–75 µg/kg Orange 2 µg/kg
	Chocolate Cake 3–57 µg/kg Blueberry Muffin 3–4 µg/kg Sweet Roll 3 µg/kg Chocolate Chip Cookies 2–4 µg/kg Apple Pie 2–4 µg/kg Doughnuts 3 µg/kg
	Tuna 9–11 µg/kg
Cereals 3 µg/kg Grain-based Foods 0.9 µg/kg	Cereal 3 µg/kg
	Popcorn 4–8 µg/kg French Fries 3 µg/kg Potato Chips 4–140 µg/kg Coleslaw 3 µg/kg

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**2.3.6. Biological Monitoring**

Biological monitoring studies have detected TCE in human blood and urine in the United States and other countries such as Croatia, China, Switzerland, and Germany (IARC, 1995). Concentrations of TCE in persons exposed through occupational degreasing operations were most likely to have detectable levels (IARC, 1995). In 1982, 8 of 8 human breastmilk samples from 4 United States urban areas had detectable levels of TCE. The levels of TCE detected, however, are not specified (HSDB, 2002; ATSDR, 1997a).



1 The Third National Health and Nutrition Examination Survey (NHANES III) examined  
 2 TCE concentrations in blood in 677 nonoccupationally exposed individuals. The individuals  
 3 were drawn from the general U.S. population and selected on the basis of age, race, gender and  
 4 region of residence (IARC, 1995; Ashley et al., 1994). The samples were collected during 1988  
 5 to 1994. TCE levels in whole blood were below the detection limit of 0.01 µg/L for about 90%  
 6 of the people sampled (see Table 2-10). Assuming that nondetects equal half of the detection  
 7 limit, the mean concentration was about 0.017 µg/L.

8  
 9 **Table 2-10. TCE levels in whole blood by population percentile**

Percentiles	10	20	30	40	50	60	70	80	90
Concentration (µg/L)	ND	ND	ND	ND	ND	ND	ND	ND	0.012

11  
 12 ND = Nondetect, i.e., below detection limit of 0.01 µg/L.  
 13 Data from IARC (1995) and Ashley (1994).

14  
 15  
 16 **2.4. EXPOSURE PATHWAYS AND LEVELS**

17 **2.4.1. General Population**

18 Because of the pervasiveness of TCE in the environment, most people are likely to have  
 19 some exposure via one or more of the following pathways: ingestion of drinking water,  
 20 inhalation of outdoor/indoor air, or ingestion of food (ATSDR, 1997a). As noted earlier, the  
 21 NHANES survey suggests that about 10% of the population has detectable levels of TCE in  
 22 blood. Each pathway is discussed below.

23  
 24 **2.4.1.1. Inhalation**

25 As discussed earlier, U.S. EPA has estimated emissions and modeled air concentrations  
 26 for the Criteria Pollutants and Hazardous Air Pollutants under the National-Scale Air Toxics  
 27 Assessment program (U.S. EPA, 2007a). This program has also estimated inhalation exposures  
 28 on a nationwide basis. The exposure estimates are based on the modeled concentrations from  
 29 outdoor sources and human activity patterns (U.S. EPA, 2005). Table 2-11 shows the 1999  
 30 results for TCE.

1 **Table 2-11. Modeled 1999 annual exposure concentrations ( $\mu\text{g}/\text{m}^3$ ) for**  
 2 **trichloroethylene**  
 3

Percentile	Exposure concentration ( $\mu\text{g}/\text{m}^3$ )		
	Rural areas	Urban areas	Nationwide
5	0.030	0.048	0.038
10	0.034	0.054	0.043
25	0.038	0.065	0.056
50	0.044	0.086	0.076
75	0.053	0.122	0.113
90	0.070	0.189	0.172
95	0.097	0.295	0.262
Mean	0.058	0.130	0.116

4 Percentiles and mean are based on census tract values.  
 5 Source: <http://www.epa.gov/ttn/atw/nata/ted/exporisk.html#indb>.  
 6  
 7  
 8

9 These modeled inhalation exposures would have a geographic distribution similar to that  
 10 of the modeled air concentrations as shown in Figure 2-4. Table 2-11 indicates that TCE  
 11 inhalation exposures in urban areas are generally about twice as high as rural areas. While these  
 12 modeling results are useful for understanding the geographic distribution of exposures, they  
 13 appear to underestimate actual exposures. This is based on the fact that, as discussed earlier, the  
 14 modeled ambient air levels are generally lower than measured values. Also, the modeled  
 15 exposures do not consider indoor sources. Indoor sources of TCE make the indoor levels higher  
 16 than ambient levels. This is particularly important to consider since people spend about 90% of  
 17 their time indoors (U.S. EPA, 1997). A number of measurement studies were presented earlier  
 18 that showed higher TCE levels indoors than outdoors. Sexton et al. (2005) measured TCE levels  
 19 in Minneapolis/St. Paul area and found means of  $0.5 \mu\text{g}/\text{m}^3$  indoors ( $n = 292$ ) and  $1.0 \mu\text{g}/\text{m}^3$   
 20 based on personal sampling ( $n = 288$ ). Using  $1.0 \mu\text{g}/\text{m}^3$  and an average adult inhalation rate of  
 21  $13 \text{ m}^3$  air/day (U.S. EPA, 1997) yields an estimated intake of  $13 \mu\text{g}/\text{day}$ . This is consistent with  
 22 ATSDR (1997a), which reports an average daily air intake for the general population of 11 to  
 23  $33 \mu\text{g}/\text{day}$ .  
 24

25 **2.4.1.2. Ingestion**

26 The median value from the nationwide survey of domestic and public wells by USGS for  
 27 1985–2001 is  $0.15 \mu\text{g}/\text{L}$ . This value was selected for exposure estimation purposes because it

1 was the most current and most representative of the national population. Using this value and an  
2 average adult water consumption rate of 1.4 L/d (this is from U.S. EPA, 1997, but note that  
3 U.S. EPA (2004) indicates a mean per capita daily average total water ingestion from all sources  
4 of 1.233 L) yields an estimated intake of 0.2 µg/day. This is lower than the ATSDR (1997a)  
5 estimate water intake for the general population of 2 to 20 µg/day. The use of the USGS survey  
6 to represent drinking water is uncertain in two ways. First, the USGS survey measured only  
7 groundwater and some drinking water supplies use surface water. Second, the USGS measured  
8 TCE levels at the well head, not the drinking water tap. Further discussion about the possible  
9 extent and magnitude of TCE exposure via drinking water is presented below.

10 According to ATSDR (1997a), TCE is the most frequently reported organic contaminant  
11 in ground water (ATSDR, 1997a), and between 9 and 34% of the drinking water supply sources  
12 tested in the United States may have some TCE contamination. Approximately 90% of the  
13 155,000 public drinking water systems<sup>1</sup> in the United States are ground water systems. The  
14 drinking water standard for TCE only applies to community water systems (CWSs) and  
15 approximately 78% of the 51,972 CWSs in the United States are ground water systems  
16 (U.S. EPA, 2008). Although commonly detected in water supplies, the levels are generally low  
17 because, as discussed earlier, MCL violations for TCE in public water supplies are relatively rare  
18 for any extended period (U.S. EPA, 1998). The USGS (2006) survey found that the number of  
19 samples exceeding the MCL (5 µg/L) was 6 at domestic wells ( $n = 2,400$ ) and 9 at public wells  
20 ( $n = 1,100$ ). Private wells, however, are often not closely monitored and if located near TCE  
21 disposal/contamination sites where leaching occurs, may have undetected contamination levels.  
22 About 10% of Americans (27 million people) obtain water from sources other than public water  
23 systems, primarily private wells (U.S. EPA, 1995). TCE is a common contaminant at Superfund  
24 sites. It has been identified in at least 861 of the 1,428 hazardous waste sites proposed for  
25 inclusion on the U.S. EPA National Priorities List (NPL) (ATSDR, 1997a). Studies have shown  
26 that many people live near these sites: 41 million people live less than 4 miles from one or more  
27 of the nation's NPL sites, and on average 3,325 people live within 1 mile of any given NPL site  
28 (ATSDR, 1996b).

29 Table 2-12 presents preliminary estimates of TCE intake from food. They are based on  
30 average adult food ingestion rates and food data from Table 2-9. This approach suggests a total  
31 ingestion intake of about 5 µg/d. It is important to consider this estimate as preliminary because  
32 it is derived by applying data from very limited food samples to broad classes of food.

---

<sup>1</sup> Public water systems (PWSs) are defined as systems which provide water for human consumption through pipes or other constructed conveyances to at least 15 service connections or serves an average of at least 25 people for at least 60 days a year. U.S. EPA further specifies three types of PWSs, including Community Water System (CWS)—a PWS that supplies water to the same population year-round.

1 **Table 2-12. Preliminary estimates of TCE intake from food ingestion**

2

	Consumption rate (g/kg-d)	Consumption rate (g/d)	Concentration in food (µg/kg)	Intake (µg/d)
Fruit	3.4	238	2	0.48
Vegetables	4.3	301	3	0.90
Fish		20	10	0.20
Meat	2.1	147	5	0.73
Dairy products	8	560	3	1.68
Grains	4.1	287	3	0.86
Sweets	0.5	35	3	0.10
Total				4.96

3  
4 <sup>a</sup>Consumption rates are per capita averages from U.S. EPA (1997).

5 <sup>b</sup>Consumption rates in g/d assume 70 kg body weight.

6  
7  
8 **2.4.1.3. Dermal**

9 TCE in bathing water and consumer products can result in dermal exposure. A modeling  
10 study has suggested that a significant fraction of the total dose associated with exposure to  
11 volatile organics in drinking water results from dermal absorption (Brown et al., 1984).  
12 U.S. EPA (2004) used a prediction model based on octanol-water partitioning and molecular  
13 weight to derive a dermal permeability coefficient for TCE in water of 0.012 cm/hour. U.S. EPA  
14 used this value to compute the dermally absorbed dose from a 35 minute shower and compared it  
15 to the dose from drinking 2 L of water at the same concentration. This comparison indicated that  
16 the dermal dose would be 17% of the oral dose. Much higher dermal permeabilities were  
17 reported by Nakai et al. (1999) based on human skin *in vitro* testing. For dilute aqueous  
18 solutions of TCE, they measured a permeability coefficient of 0.12 cm/hour (26°C). Nakai et al.  
19 (1999) also measured a permeability coefficient of 0.018 cm/hour for tetrachloroethylene in  
20 water. Poet et al. (2000) measured dermal absorption of TCE in humans from both water and  
21 soil matrices. The absorbed dose was estimated by applying a physiologically based  
22 pharmacokinetic model to TCE levels in breath. The permeability coefficient was estimated to  
23 be 0.015 cm/hour for TCE in water and 0.007 cm/hour for TCE in soil (Poet et al., 2000).

1 **2.4.1.4. Exposure to TCE Related Compounds**

2 Table 2-13 presents adult exposure estimates that have been reported for the TCE related  
 3 compounds. This table was originally compiled by Wu and Schaum (2001). The exposure/dose  
 4 estimates are taken directly from the listed sources or derived based on monitoring data  
 5 presented in the source documents. They are considered “preliminary” because they are  
 6 generally based on very limited monitoring data. These preliminary estimates suggest that  
 7 exposures to most of the TCE related compounds are comparable to or greater than TCE itself.  
 8

9 **Table 2-13. Preliminary intake estimates of TCE and TCE-related chemicals**  
 10

Chemical	Population	Media	Range of estimated adult exposures (µg/day)	Range of adult doses (mg/kg/d)	Data sources <sup>a</sup>
Trichloroethylene (TCE)	General	Air	11–33	1.57E-04–4.71E-04	ATSDR, 1997a
	General	Water	2–20 <sup>b</sup>	2.86E-05–2.86E-04	ATSDR, 1997a
	Occupational	Air	2,232–9,489	3.19E-02–1.36E-01	ATSDR, 1997a
Tetrachloroethylene (PERC)	General	Air	80–200	1.14E-03–2.86E-03	ATSDR, 1997b
	General	Water	0.1–0.2	1.43E-06–2.86E-06	ATSDR, 1997b
	Occupational	Air	5,897–219,685	8.43E-02–3.14	ATSDR, 1997b
1,1,1-Trichloroethane	General	Air	10.8–108	1.54E-04–1.54E-03	ATSDR, 1995
	General	Water	0.38–4.2	5.5E-06–6.00E-05	ATSDR, 1995
1,2-Dichloroethylene	General	Air	1–6	1.43E-05–8.57E-05	ATSDR, 1996a
	General	Water	2.2	3.14E -05	ATSDR, 1996a
Cis-1,2-Dichloroethylene	General	Air	5.4	7.71E -05	HSDB, 1996
	General	Water	0.5–5.4	7.14E-06–7.71E-05	HSDB, 1996
1,1,1,2-Tetrachloroethane	General	Air	142	2.03E -03	HSDB, 2002
1,1-Dichloroethane	General	Air	4	5.71E -05	ATSDR, 1990
	General	Water	2.47–469.38	3.53E-05–6.71E-03	ATSDR, 1990
Chloral	General	Water	0.02–36.4	2.86E-07–5.20E-04	HSDB, 1996
Monochloroacetic acid	General	Water	2–2.4	2.86E-05–3.43E-05	U.S. EPA, 1994
Dichloroacetic acid	General	Water	10–266	1.43E-04–3.80E-03	IARC, 1995
Trichloroacetic acid	General	Water	8.56–322	1.22E-03–4.60E-03	IARC, 1995

11 <sup>a</sup>Originally compiled in Wu and Schaum (2001).  
 12

13 <sup>b</sup>New data from USGS (2006) suggests much lower water intakes, i.e., 0.2 µg/d.  
 14  
 15

## 2.4.2. Potentially Highly Exposed Populations

Some members of the general population may have elevated TCE exposures. ATSDR (1997a) has reported that TCE exposures may be elevated for people living near waste facilities where TCE may be released, residents of some urban or industrialized areas, people exposed at work (discussed further below) and individuals using certain products (also discussed further below). Because TCE has been detected in breast milk samples of the general population, infants who ingest breast milk may be exposed, as well. Increased TCE exposure is also a possible concern for bottle-fed infants because they ingest more water on a bodyweight basis than adults (the average water ingestion rate for adults is 21 mL/kg-d and for infants under one year old it is 44 mL/kg-d—U.S. EPA, 1997). Also, because TCE can be present in soil, children may be exposed through activities such as playing in or ingesting soil.

### 2.4.2.1. Occupational Exposure

Occupational exposure to TCE in the United States has been identified in various degreasing operations, silk screening, taxidermy, and electronics cleaning (IARC, 1995). The major use of trichloroethylene is for metal cleaning or degreasing (IARC, 1995). Degreasing is used to remove oils, greases, waxes, tars, and moisture before galvanizing, electroplating, painting, anodizing, and coating. The five primary industries using TCE degreasing are furniture and fixtures; electronic and electric equipment; transport equipment; fabricated metal products; and miscellaneous manufacturing industries (IARC, 1995). Additionally, TCE is used in the manufacture of plastics, appliances, jewelry, plumbing fixtures, automobile, textiles, paper, and glass (IARC, 1995).

Table 2-13 lists the primary types of industrial degreasing procedures and the years that the associated solvents were used. Vapor degreasing has the highest potential for exposure because vapors can escape into the work place. Hot dip tanks, where trichloroethylene is heated to close to its boiling point of 87°C, are also major sources of vapor that can create exposures as high as vapor degreasers. Cold dip tanks have a lower exposure potential, but they have a large surface area which enhances volatilization. Small bench-top cleaning operations with a rag or brush and open bucket have the lowest exposure potential. In combination with the vapor source, the size and ventilation of the workroom are the main determinants of exposure intensity (NRC, 2006).

Occupational exposure to TCE has been assessed in a number of epidemiologic studies. Studies of aircraft workers show short term peak exposures in the hundreds of ppm (>540 mg/m<sup>3</sup>) and long term exposures in the low tens of ppm (>54 mg/m<sup>3</sup>) (Spirtas et al., 1991; Blair et al., 1998; Garabrant et al., 1988; Morgan et al., 1998; and Boice et al., 1998). Similar exposures have been reported for cardboard/paperboard workers (Henschler et al., 1995; Sinks et

1 al., 1992) and uranium processors (Ritz, 1999). ATSDR (1997a) reports that the majority of  
 2 published worker exposure data show time-weighted average (TWA) concentrations ranging  
 3 from <50 ppm to 100 ppm (<270–540 mg/m<sup>3</sup>). National Institute of Occupational Safety and  
 4 Health conducted a survey of various industries from 1981 to 1983 and estimated that  
 5 approximately 401,000 U.S. employees in 23,225 plants in the United States were potentially  
 6 exposed to TCE during this timeframe (IARC, 1995; ATSDR, 1997a).

7 Occupational exposure to TCE has likely declined since the 1950's and 1960's due to  
 8 decreased usage, better release controls and improvements in worker protection. Reductions in  
 9 TCE use are illustrated in Table 2-14, which shows that by about 1980 common degreasing  
 10 operations had substituted other solvents for TCE.

11  
 12 **Table 2-14. Years of solvent use in industrial degreasing and cleaning**  
 13 **operations**  
 14

Years	Vapor degreasers	Cold dip tanks	Rag or brush and bucket on bench top
~1934–1954	Trichloroethylene (poorly controlled)	Stoddard solvent*	Stoddard solvent (general use), alcohols (electronics shop), carbon tetrachloride (instrument shop).
~1955–1968	Trichloroethylene (poorly controlled, tightened in 1960s)	Trichloroethylene (replaced some Stoddard solvent)	Stoddard solvent, trichloroethylene (replaced some Stoddard solvent), perchloroethylene, 1,1,1-trichloroethane (replaced carbon tetrachloride, alcohols, ketones).
~1969–1978	Trichloroethylene, (better controlled)	Trichloroethylene, Stoddard solvent	Trichloroethylene, perchloroethylene, 1,1,1-trichloroethane, alcohols, ketones, Stoddard solvent.
~1979–1990s	1,1,1-Trichloroethane (replaced trichloroethylene)	1,1,1-Trichloroethane (replaced trichloroethylene), Stoddard solvent	1,1,1-Trichloroethane, perchloroethylene, alcohols, ketones, Stoddard solvent.

15  
 16 \* A mixture of straight and branched chain paraffins (48%), naphthenes (38%), and aromatic hydrocarbons (14%).  
 17 Source: Stewart and Dosemeci (2005).  
 18  
 19

20 **2.4.2.2. Consumer Exposure**

21 Consumer products reported to contain TCE include wood stains, varnishes, and finishes;  
 22 lubricants; adhesives; typewriter correction fluids; paint removers; and cleaners (ATSDR,  
 23 1997a). Use of TCE has been discontinued in some consumer products (i.e., as an inhalation  
 24 anesthetic, fumigant, and an extractant for decaffeinating coffee) (ATSDR, 1997a).

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1 **2.4.3. Exposure Standards**

2 Table 2-15 summarizes the federal regulations limiting TCE exposure.

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4  
5

**Table 2-15. TCE standards**

Standard	Value	Reference
OSHA Permissible Exposure Limit: Table Z-2 8-hour time-weighted average.	100 ppm (538 mg/m <sup>3</sup> )	29 CFR 1910.1000 (7/1/2000)
OSHA Permissible Exposure Limit: Table Z-2 Acceptable ceiling concentration (this cannot be exceeded for any time period during an 8-hour shift except as allowed in the maximum peak standard below).	200 ppm (1076 mg/m <sup>3</sup> )	29 CFR 1910.1000 (7/1/2000)
OSHA Permissible Exposure Limit: Table Z-2 Acceptable maximum peak above the acceptable ceiling concentration for an 8-hour shift. Maximum Duration: 5 minutes in any 2 hours.	300 ppm (1614 mg/m <sup>3</sup> )	29 CFR 1910.1000 (7/1/2000)
MCL under the Safe Drinking Water Act.	5 ppb (5 µg/L)	40 CFR 141.161
FDA Tolerances for decaffeinated ground coffee decaffeinated soluble (instant) coffee extract spice oleoresins.	25 ppm (25 µg/g) 10 ppm (10 µg/g) 30 ppm (30 µg/g)	21 CFR 173.290 (4/1/2000)

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**2.5. EXPOSURE SUMMARY**

9 TCE is a volatile compound with moderate water solubility. Most TCE produced today  
10 is used for metal degreasing. The highest environmental releases are to the air. Ambient air  
11 monitoring data suggests that levels have remained fairly constant since 1999 at about 0.3 µg/m<sup>3</sup>.  
12 Indoor levels are commonly 3 or more times higher than outdoor levels due to releases from  
13 building materials and consumer products. TCE is among the most common groundwater  
14 contaminants and the median level based on a large survey by USGS for 1985–2001 is  
15 0.15 µg/L. It has also been detected in a wide variety of foods in the 1–100 µg/kg range. None  
16 of the environmental sampling has been done using statistically based national surveys.  
17 However, a substantial amount of air and groundwater data have been collected allowing  
18 reasonably well supported estimates of typical daily intakes by the general population:  
19 inhalation—13 µg/day and water ingestion—0.2 µg/day. The limited food data suggests an  
20 intake of about 5 µg/day, but this must be considered preliminary.

21 Much higher exposures have occurred to various occupational groups. For example, past  
22 studies of aircraft workers have shown short term peak exposures in the hundreds of ppm



1 (>540,000 µg/m<sup>3</sup>) and long term exposures in the low tens of ppm (>54,000 µg/m<sup>3</sup>).  
2 Occupational exposures have likely decreased in recent years due to better release controls and  
3 improvements in worker protection.

4 Preliminary exposure estimates were presented for a variety of TCE related compounds  
5 which include metabolites of TCE and other parent compounds that produce similar metabolites.  
6 Exposure to the TCE related compounds can alter or enhance TCE's metabolism and toxicity by  
7 generating higher internal metabolite concentrations than would result from TCE exposure by  
8 itself. The preliminary estimates suggest that exposures to most of the TCE related compounds  
9 are comparable to or greater than TCE itself.