



**TOXICOLOGICAL REVIEW**

**OF**

**TRICHLOROETHYLENE**

**CHAPTER 2**

(CAS No. 79-01-6)

**In Support of Summary Information on the  
Integrated Risk Information System (IRIS)**

*September 2011*

## 2. EXPOSURE CHARACTERIZATION

The purpose of this exposure characterization is to summarize information about TCE sources, releases, media levels, and exposure pathways for the general population (occupational exposure is also discussed to a lesser extent). It is not meant as a substitute for a detailed exposure assessment for a particular risk assessment application. While this section primarily addresses TCE, it also includes some information on a number of related compounds. These related compounds include metabolites of TCE and other parent compounds that produce similar metabolites as shown in Table 2-1. The first column in this table lists the principal TCE metabolites in humans (trichloroethanol, trichloroethanol-glucuronide, and trichloroacetic acid) as well as a number of minor metabolites ([ATSDR, 1997c](#)). The subsequent columns list parent compounds that can produce some of the same metabolites. The metabolic reaction pathways are much more complicated than implied here and it should be understood that this table is intended only to provide a general understanding of which parent compounds lead to which TCE metabolites. Exposure to the TCE-related compounds can alter or enhance TCE's metabolism and toxicity by generating higher internal metabolite concentrations than would result from TCE exposure by itself. This characterization is based largely on earlier work by Wu and Schaum ([2001, 2000](#)), but also provides updates in a number of areas.

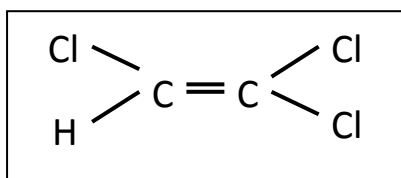
**Table 2-1. TCE metabolites and related parent compounds<sup>a</sup>**

| 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                          |                       |

<sup>a</sup>X indicates that the parent compound can produce the corresponding metabolite (Hazardous Substances Data Bank, <http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB>).

### 2.1. ENVIRONMENTAL SOURCES

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



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

**Table 2-2. Chemical properties of TCE**

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

TCE has been produced commercially since the 1920s in many countries by chlorination of ethylene or acetylene. Its use in vapor degreasing began in the 1920s. In the 1930s, it was introduced for use in dry cleaning. This use was largely discontinued in the 1950s and was replaced with tetrachloroethylene ([ATSDR, 1997c](#)). More recently, 80–90% of TCE production worldwide is used for degreasing metals ([IARC, 1995a](#)). It is also used in adhesives, paint-stripping formulations, paints, lacquers, and varnishes ([SRI, 1992](#)). A number of past uses in cosmetics, drugs, foods, and pesticides have now been discontinued including use as an extractant for spice oleoresins, natural fats and oils, hops, and decaffeination of coffee ([IARC, 1995a](#)), and as a carrier solvent for the active ingredients of insecticides and fungicides, and for spotting fluids ([ATSDR, 1997c](#); [WHO, 1985](#)). The production of TCE in the United States peaked at 280 million kg (616 million pounds) in 1970 and declined to 60 million kg (132 million pounds) in 1998 ([USGS, 2006](#)). In 1996, the United States imported 4.5 million kg (10 million pounds) and exported 29.5 million kg (65 million pounds) ([Chemical Marketing Reporter, 1997](#)). Table 2-3 summarizes the basic properties and principal uses of the TCE related compounds.

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

|                           | Water solubility (mg/L) | Vapor pressure (mmHG) | Uses  | References                       |
|---------------------------|-------------------------|-----------------------|---|----------------------------------|
| Tetrachloroethylene       | 150                     | 18.5 @25°C            | Dry cleaning, degreasing, solvent                     | Wu and Schaum (2001)             |
| 1,1,1-Trichloroethane     | 4,400                   | 124 @25°C             | Solvents, degreasing                                  | Wu and Schaum (2001)             |
| 1,2-Dichloroethylene      | 3,000–6,000             | 273–395 @30°C         | Solvents, chemical intermediates                      | Wu and Schaum (2001)             |
| 1,1,1,2-Tetrachloroethane | 1,100                   | 14 @25°C              | Solvents, but currently not produced in United States | HSDB, 2002; Wu and Schaum (2001) |
| 1,1-Dichloroethane        | 5,500                   | 234 @25°C             | Solvents, chemical intermediates                      | Wu and Schaum (2001)             |
| Chloral                   | High                    | 35 @20°C              | Herbicide production                                  | Wu and Schaum (2001)             |
| Chloral hydrate           | High                    | NA                    | Pharmaceutical production                             | Wu and Schaum (2001)             |
| Monochloroacetic acid     | High                    | 1 @43°C               | Pharmaceutical production                             | Wu and Schaum (2001)             |
| Dichloroacetic acid       | High                    | <1 @20°C              | Pharmaceuticals, not widely used                      | Wu and Schaum (2001)             |
| Trichloroacetic acid      | High                    | 1 @50°C               | Herbicide production                                  | Wu and Schaum (2001)             |
| Oxalic acid               | 220,000                 | 0.54 @105°C           | Scouring/cleaning agent, degreasing                   | HSDB (2002)                      |
| Dichlorovinyl cysteine    | Not available           | Not available         | Not available   |                                  |
| Trichloroethanol          | Low                     | NA                    | Anesthetics and chemical intermediate                 | Hawley and Lewis (2001)          |

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

**Table 2-4. TRI releases of TCE (pounds/year)**

| Yr   | 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   |

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

Under the National-Scale Air Toxics Assessment (NSATA) program, EPA has developed an emissions inventory for TCE (U.S. EPA, 2007a). The inventory includes sources in the United States plus the Commonwealth of Puerto Rico and the U.S. Virgin Islands. The types of emission sources in the inventory include large facilities, such as waste incinerators and factories and smaller sources, such as dry cleaners and small manufacturers. Figures 2-2 and 2-3 show the results of the 1999 emissions inventory for TCE. Figure 2-2 shows the percent contribution to total emissions by source category. A variety of sources have TCE emissions with the largest ones identified as halogenated solvent cleaners and metal parts and products. Figure 2-3 shows a national map of the emission density (tons/square miles/year) for TCE. This map shows the highest densities in the far west and northeastern regions of the United States. Emissions range from 0 to 4.12 tons/square miles/year.

# Trichloroethylene Emissions 1999

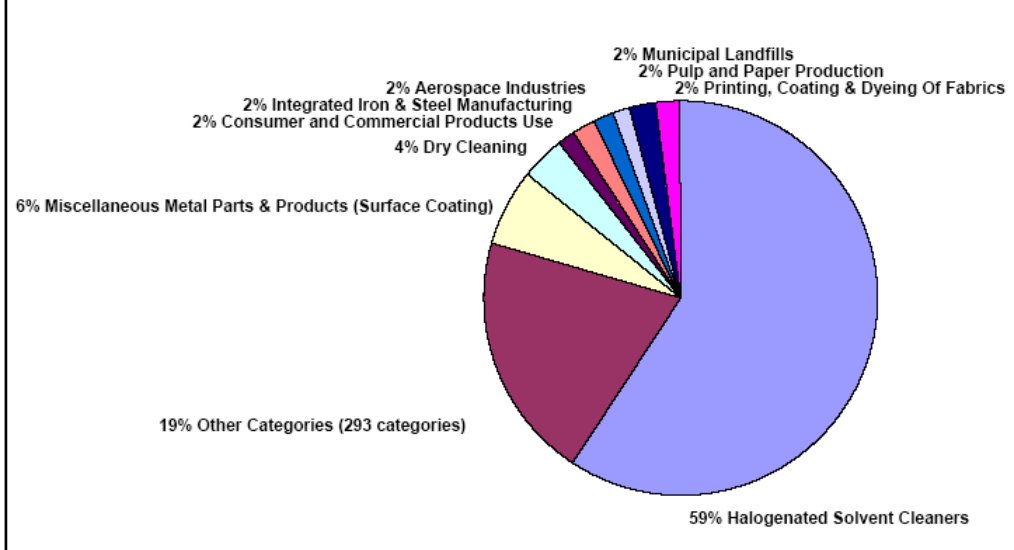


Figure 2-2. Source contribution to TCE emissions.

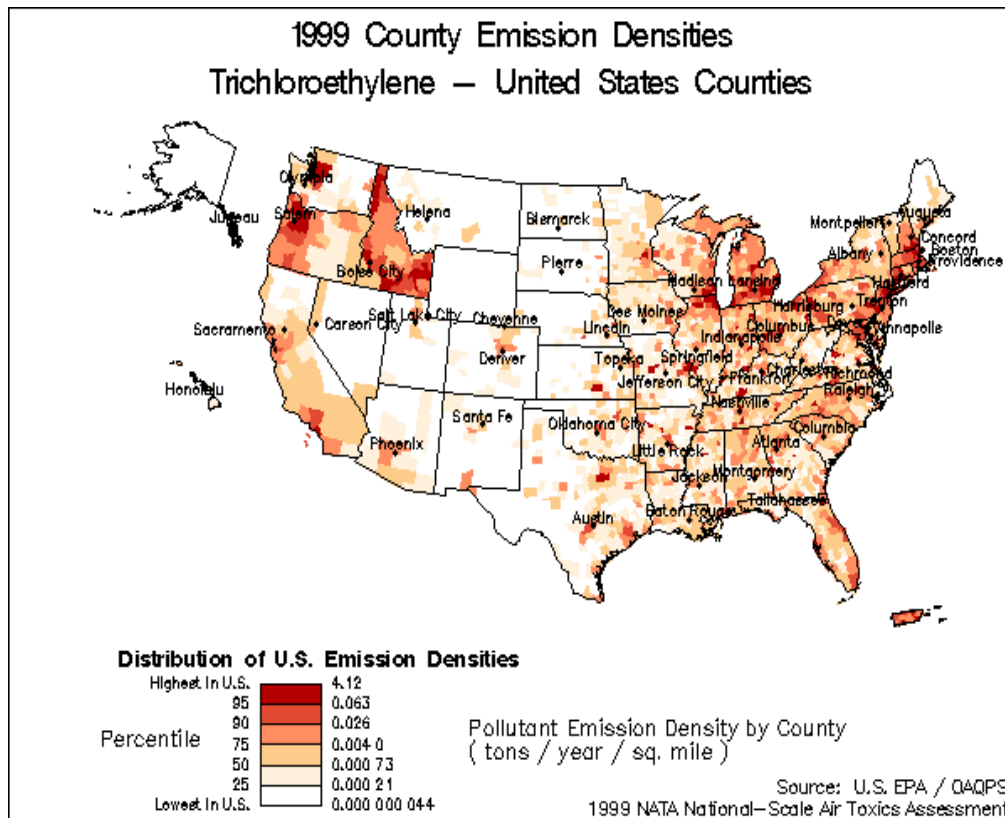


Figure 2-3. Annual emissions of TCE.

## **2.2. ENVIRONMENTAL FATE**

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

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

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

In the atmosphere, TCE is expected to be present primarily in the vapor phase, rather than sorbed to particulate, because of its high vapor pressure. Some removal by scavenging during wet precipitation is expected because of its moderate water solubility. The major degradation process affecting vapor-phase TCE is photo-oxidation by hydroxyl radicals. Photolysis in the atmosphere proceeds very slowly, if at all. TCE does not absorb ultraviolet light at wavelengths of <290 nm and thus, will not directly photolyze. Based on measured rate data for the vapor phase photo-oxidation reaction with hydroxyl radicals, the estimated half-life of TCE in the atmosphere is on the order of 1–11 days with production of phosgene, dichloroacetyl chloride (DCAC), and formyl chloride. Under smog conditions, degradation is more rapid (half-life on the order of hours) ([HSDB, 2002](#); [Howard et al., 1991](#)).

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

The dominant fate of TCE released to surface waters is volatilization (predicted half-life of minutes to hours). Bioconcentration, biodegradation, and sorption to sediments and suspended solids are not thought to be significant ([HSDB, 2002](#)). TCE is not hydrolyzed under normal environmental conditions. However, slow photo-oxidation in water (half-life of 10.7 months) has been reported ([HSDB, 2002](#); [Howard et al., 1991](#)).

## **2.3. EXPOSURE CONCENTRATIONS**

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

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

TCE has been detected in the air throughout the United States. According to ATSDR ([1997c](#)), atmospheric levels are highest in areas concentrated with industry and population, and

lower in remote and rural regions. Table 2-5 shows levels of TCE measured in the ambient air at a variety of locations in the United States.

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

| Area                                      | Yr        | Concentration ( $\mu\text{g}/\text{m}^3$ ) |            |
|---|-----------|--|------------|
|   |           | Mean                                       | Range      |
| <b><i>Rural</i></b>                       |           |  |            |
| Whiteface Mountain, New York <sup>a</sup> | 1974      | 0.5  | <0.3–1.9   |
| Badger Pass, California <sup>a</sup>      | 1977      | 0.06                                       | 0.005–0.09 |
| Reese River, Nevada <sup>a</sup>          | 1977      | 0.06                                       | 0.005–0.09 |
| Jetmar, Kansas <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>                   | 1973–1979 | 9.1  | ND–97      |
| New York City, New York <sup>a</sup>      | 1974      | 3.8  | 0.6–5.9    |
| Los Angeles, California <sup>a</sup>      | 1976      | 1.7  | 0.14–9.5   |
| Lake Charles, Louisiana <sup>a</sup>      | 1976–1978 | 8.6  | 0.4–11.3   |
| Phoenix, Arizona <sup>a</sup>             | 1979      | 2.6  | 0.06–16.7  |
| Denver, Colorado <sup>a</sup>             | 1980      | 1.07                                       | 0.15–2.2   |
| St. Louis, Missouri <sup>a</sup>          | 1980      | 0.6  | 0.1–1.3    |
| Portland, Oregon <sup>a</sup>             | 1984      | 1.5  | 0.6–3.9    |
| Philadelphia, Pennsylvania <sup>a</sup>   | 1983–1984 | 1.9  | 1.6–2.1    |
| Southeast Chicago, Illinois <sup>b</sup>  | 1986–1990 | 1.0  |            |
| East St. Louis, Illinois <sup>b</sup>     | 1986–1990 | 2.1  |            |
| District of Columbia <sup>c</sup>         | 1990–1991 | 1.94                                       | 1–16.65    |
| Urban Chicago, Illinois <sup>d</sup>      | pre–1993  | 0.82–1.16                                  |            |
| Suburban Chicago, Illinois <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, Arizona <sup>g</sup>             | 1994–1996 | 0.29                                       | 0–1.53     |
| Tucson, Arizona <sup>g</sup>              | 1994–1996 | 0.23                                       | 0–1.47     |
| All urban/suburban sites                  | 1973–1996 |  | 0–97       |

<sup>a</sup>IARC (1995a).

<sup>b</sup>Sweet (1992).

<sup>c</sup>Hendler (1992).

<sup>d</sup>Scheff (1993).

<sup>e</sup>Shah (1988).

<sup>f</sup>Bunce (1994).

<sup>g</sup>Zielinska-Psuja (1998).

ND = nondetect

More recent ambient air measurement data for TCE were obtained from EPA's Air Quality System database at the AirData Web site: <http://www.epa.gov/air/data/index.html> (2007b). These data were collected from a variety of sources including state and local environmental agencies. The data are not from a statistically based survey and cannot be assumed to provide nationally representative values. The most recent data (2006) come from 258 monitors located in 37 states. The means for these monitors range from 0.03 to 7.73  $\mu\text{g}/\text{m}^3$



and have an overall average of 0.23  $\mu\text{g}/\text{m}^3$ . Table 2-6 summarizes the data for the years 1999–2006. The data suggest that levels have remained fairly constant since 1999 at about 0.3  $\mu\text{g}/\text{m}^3$ . Table 2-7 shows the monitoring data organized by land setting (rural, suburban, or urban) and land use (agricultural, commercial, forest, industrial, mobile, and residential). Urban air levels are almost 4 times higher than rural areas. Among the land use categories, TCE levels are highest in commercial/industrial areas and lowest in forest areas.

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

| Yr   | 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  |

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

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

|   | 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         |

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

### 2.3.2. Outdoor Air—Modeled Levels

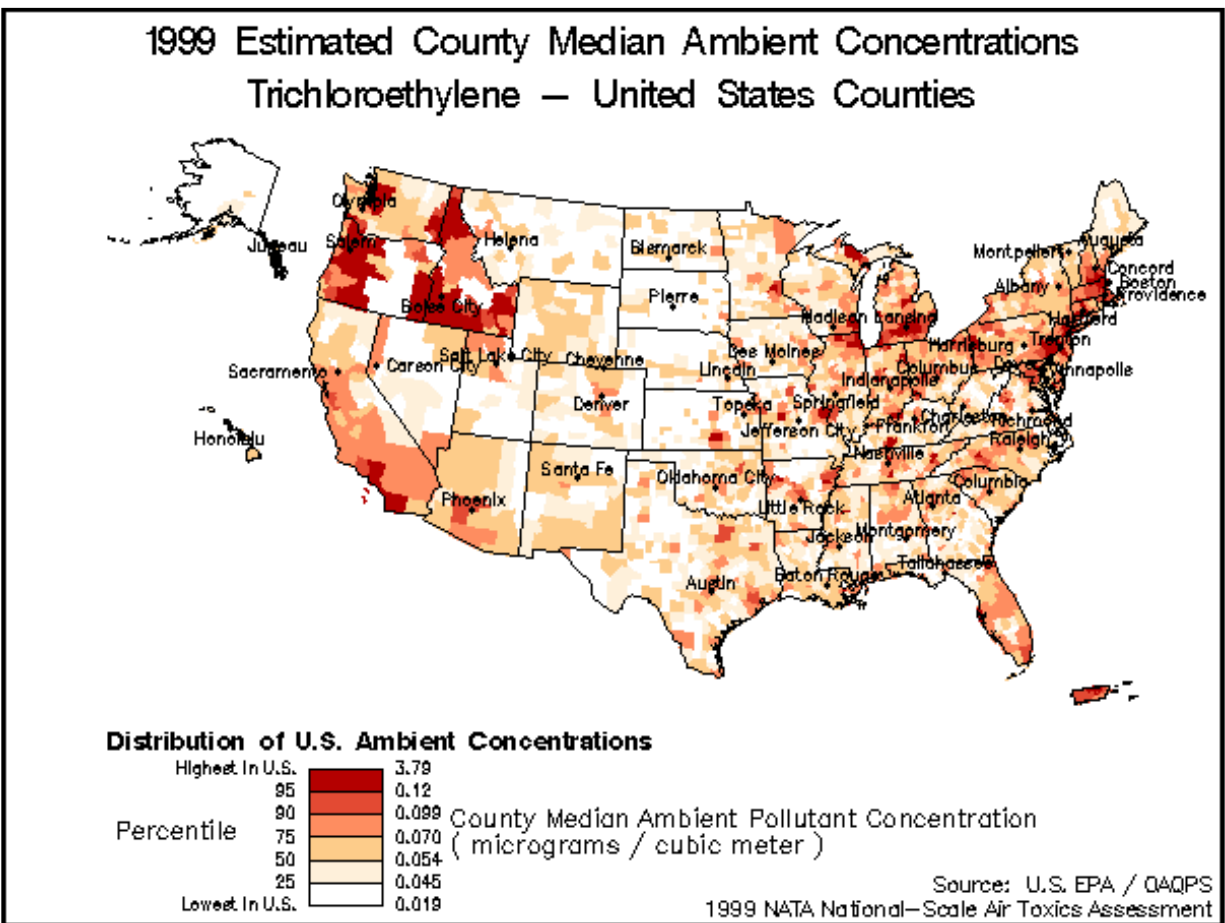
Under the National-Scale Air Toxics Assessment program, EPA has compiled emissions data and modeled air concentrations/exposures for the Criteria Pollutants and Hazardous Air Pollutants (U.S. EPA, 2007a). The results of the 1999 emissions inventory for TCE were discussed earlier and results presented 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 (<http://www.epa.gov/ttnatw01/nata/aspn.html>). This model is based on the 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 (see 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 EPA (2007a) which presents a comparison of modeling results from NSATA to measured values at the same locations. For 1999, it was found that formaldehyde levels were underestimated at 79% of the sites ( $n = 92$ ). Thus, while the NSATA modeling results are useful for understanding geographic distributions, they may frequently underestimate ambient levels.



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

### 2.3.3. Indoor Air

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

- The 1987 EPA Total Exposure Assessment Methodology study ([Wallace, 1987](#)) showed that the ratio of indoor to outdoor TCE concentrations for residences in Greensboro, NC, was about 5:1.
- In two homes using well water with TCE levels averaging 22–128  $\mu\text{g}/\text{L}$ , the TCE levels in bathroom air ranged from <500–40,000  $\mu\text{g}/\text{m}^3$  when the shower ran <30 minutes ([Andelman, 1985](#)).
- Shah and Singh ([1988](#)) report an average indoor level of 7.2  $\mu\text{g}/\text{m}^3$  based on over 2,000 measurements made in residences and workplaces during 1981–1984 from various locations across the United States.
- Hers et al. ([2001](#)) provides a summary of indoor air TCE measurements at locations in United States, Canada, and Europe with a range of <1–165  $\mu\text{g}/\text{m}^3$ .

- Sapkota et al. (2005) measured TCE levels inside and outside of the Baltimore Harbor Tunnel toll booths during the summer of 2001. Mean TCE levels were 3.11  $\mu\text{g}/\text{m}^3$  indoors and 0.08  $\mu\text{g}/\text{m}^3$  outdoors based on measurements on 7 days. The authors speculated that indoor sources, possibly dry cleaning residues on uniforms, were the primary source of the indoor TCE.
- Sexton et al. (2005) measured TCE levels inside and outside residences in Minneapolis/St. Paul metropolitan area. Two day samples were collected over three seasons in 1999. Mean TCE levels were 0.5  $\mu\text{g}/\text{m}^3$  indoors ( $n = 292$ ), 0.2  $\mu\text{g}/\text{m}^3$  outdoors ( $n = 132$ ) and 1.0  $\mu\text{g}/\text{m}^3$  based on personal sampling ( $n = 288$ ).
- Zhu et al. (2005) measured TCE levels inside and outside of residences in Ottawa, Canada. Seventy-five homes were randomly selected and measurements were made during the winter of 2002/2003. TCE was above detection limits in the indoor air of 33% of the residences and in the outdoor air of 19% of the residences. The mean levels were 0.06  $\mu\text{g}/\text{m}^3$  indoors and 0.08  $\mu\text{g}/\text{m}^3$  outdoors. Given the high frequency of nondetects, a more meaningful comparison can be made on basis of the 75<sup>th</sup> percentiles: 0.08  $\mu\text{g}/\text{m}^3$  indoors and 0.01  $\mu\text{g}/\text{m}^3$  outdoors.

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

- TCE vapor intrusion has occurred in buildings/residences near a former Smith Corona manufacturing facility located in Cortlandville, New York. An extensive sampling program conducted in 2006-2007 has detected TCE in groundwater (up to 22  $\mu\text{g}/\text{L}$ ), subslab gas (up to 1,000  $\mu\text{g}/\text{m}^3$ ), and indoor air (up to 34  $\mu\text{g}/\text{m}^3$ ) (NYSDEC, 2007).
- Evidence of vapor intrusion of TCE has also been reported in buildings and residences in Endicott, New York. Sampling in 2003 showed total volatile organic compounds (VOCs) in soil gas exceeding 10,000  $\mu\text{g}/\text{m}^3$  in some areas. Indoor air sampling detected TCE levels ranging from 1 to 140  $\mu\text{g}/\text{m}^3$  (Meyers, 2003).

Little et al. (1992) developed attenuation coefficients relating contaminants in soil gas (assumed to be in chemical equilibrium with the groundwater) to possible indoor levels as a result of vapor intrusion. On this basis they estimated that TCE groundwater levels of 540  $\mu\text{g}/\text{L}$ , (a high contamination level) could produce indoor air levels of 5–500  $\mu\text{g}/\text{m}^3$ . Vapor intrusion can be an important contributor to indoor levels in situations where residences are located near soils or groundwater with high contamination levels. EPA (2002c) recommends considering vapor intrusion when volatiles are suspected to be present in groundwater or soil at a depth of <100 feet. Hers et al. (2001) concluded that the contribution of VOCs from subsurface sources relative to indoor sources is small for most chemicals and sites.

### 2.3.4. Water

A number of early (pre-1990) studies measured TCE levels in natural water bodies (levels in drinking water are discussed later in this section) as summarized in Table 2-8.

**Table 2-8. Concentrations of TCE in water based on pre-1990 studies**

| Water type          | Location         | Yr   | Mean (µg/L) | Median (µg/L) | Range (µg/L) | Number of samples | Reference               |
|---------------------|------------------|------|-------------|---------------|--------------|-------------------|-------------------------|
| Industrial effluent | United States    | 1983 |             | 0.5           |              | NR                | IARC (1995a)            |
| Surface waters      | United States    | 1983 |             | 0.1           |              | NR                | IARC (1995a)            |
| Rainwater           | Portland, Oregon | 1984 | 0.006       |               | 0.002–0.02   | NR                | Ligoeki et al. (1985)   |
| Groundwater         | Minnesota        | 1983 |             |               | 0.2–144      | NR                | Sabel and Clark (1984)  |
|                     | New Jersey       | 1976 |             |               | ≤1,530       | NR                | Burmester et al. (1982) |
|                     | New York         | 1980 |             |               | ≤3,800       | NR                | Burmester et al. (1982) |
|                     | Pennsylvania     | 1980 |             |               | ≤27,300      | NR                | Burmester et al. (1982) |
|                     | Massachusetts    | 1976 |             |               | ≤900         | NR                | Burmester et al. (1982) |
|                     | Arizona          |      |             |               | 8.9–29       | NR                | IARC (1995a)            |
| Drinking water      | United States    | 1976 |             |               | 0.2–49       |                   | IARC (1995a)            |
|                     | United States    | 1977 |             |               | 0–53         |                   | IARC (1995a)            |
|                     | United States    | 1978 |             |               | 0.5–210      |                   | IARC (1995a)            |
|                     | Massachusetts    | 1984 |             |               | max. 267     |                   | IARC (1995a)            |
|                     | New Jersey       | 1984 | 23.4        |               | max. 67      | 1130              | Cohn et al. (1994b)     |
|                     | California       | 1985 |             |               | 8–12         | 486               | EPA, (1987)             |
|                     | California       | 1984 | 66          |               |              | 486               | EPA, (1987)             |
|                     | North Carolina   | 1984 | 5           |               |              | 48                | EPA, (1987)             |
|                     | North Dakota     | 1984 | 5           |               |              | 48                | EPA, (1987)             |

NR = not reported

According to IARC (1995a), the reported median concentrations of TCE in 1983–1984 were 0.5 µg/L in industrial effluents and 0.1 µg/L in ambient water. Results from an analysis of the EPA STORET Data Base (1980–1982) showed that TCE was detected in 28% of 9,295 surface water reporting stations nationwide (ATSDR, 1997c). A more recent search of the STORET database for TCE measurements nationwide during 2008 in streams, rivers and lakes indicated three detects (0.03–0.04 µg/L) out of 150 samples (STORET Database, <http://www.epa.gov/storet/dbtop.html>).

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

Squillace et al. (2004) reported TCE levels in shallow groundwater based on data from the National Water Quality Assessment Program managed by United States Geological Survey (USGS). Samples from 518 wells were collected from 1996 to 2002. All wells were located in

residential or commercial areas and had a median depth of 10 m. The authors reported that approximately 8.3% of the well levels were above the detection limit (level not specified), 2.3% were above 0.1 µg/L and 1.7% were above 0.2 µg/L.

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

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

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

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

(>1% of samples) include TCE, tetrachloroethylene, 1,1,1-trichloroethane (methyl chloroform), 1,2 dichloroethylene, and 1,1-dichloroethane. Findings specific to TCE include the following:

- Detection frequency was 2.6% at 0.2 µg/L and was 3.8% at 0.02 µg/L.
- The median concentration was 0.15 µg/L with a range of 0.02–100 µg/L.
- The number of samples exceeding the maximum contaminant level (5 µg/L) was six at domestic wells and nine at public wells.

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

### **2.3.5. Other Media**

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

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

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

| <b>IARC (1995a)</b>                                 | <b>Fleming-Jones and Smith (2003)</b>   |
|---|---|
| Cheese 3.8 µg/kg<br>Butter and margarine 73.6 µg/kg | Cheese 2–3 µg/kg<br>Butter 7–9 µg/kg<br>Margarine 2–21 µg/kg<br>Cheese pizza 2 µg/kg  |
| Peanut butter 0.5 µg/kg                             | Nuts 2–5 µg/kg<br>Peanut butter 4–70 µg/kg  |
|   | Ground beef 3–6 µg/kg<br>Beef frankfurters 2–105 µg/kg<br>Hamburger 5–9 µg/kg<br>Cheeseburger 7 µg/kg<br>Chicken nuggets 2–5 µg/kg<br>Bologna 2–20 µg/kg<br>Pepperoni pizza 2 µg/kg |
|   | Banana 2 µg/kg<br>Avocado 2–75 µg/kg<br>Orange 2 µg/kg  |
|   | Chocolate cake 3–57 µg/kg<br>Blueberry muffin 3–4 µg/kg<br>Sweet roll 3 µg/kg<br>Chocolate chip cookies 2–4 µg/kg<br>Apple pie 2–4 µg/kg<br>Doughnuts 3 µg/kg                       |
|   | Tuna 9–11 µg/kg   |
| Cereals 3 µg/kg<br>Grain-based foods 0.9 µg/kg      | Cereal 3 µg/kg  |
|   | Popcorn 4–8 µg/kg<br>French fries 3 µg/kg<br>Potato chips 4–140 µg/kg<br>Coleslaw 3 µg/kg   |

### 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, 1995a](#)). Concentrations of TCE in persons exposed through occupational degreasing operations were most likely to have detectable levels ([IARC, 1995a](#)). In 1982, eight of eight human breastmilk samples from four United States urban areas had detectable levels of TCE. The levels of TCE detected, however, are not specified ([HSDB, 2002](#); [ATSDR, 1997c](#)).

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



**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 |

ND = Nondetect, i.e., below detection limit of 0.01 µg/L.

Sources: IARC ([1995a](#)); Ashley et al. ([1994](#)).

## 2.4. EXPOSURE PATHWAYS AND LEVELS

### 2.4.1. General Population

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

#### 2.4.1.1. Inhalation

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

**Table 2-11. Modeled 1999 annual exposure concentrations (µg/m<sup>3</sup>) for TCE**

| Percentile | Exposure concentration (µg/m <sup>3</sup> ) |             |            |
|------------|---|-------------|------------|
|            | 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      |

Percentiles and mean are based on census tract values.

Source: <http://www.epa.gov/ttn/atw/nata/ted/exporisk.html#indb>.

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

#### **2.4.1.2. Ingestion**

The median value from the nationwide survey of domestic and public wells by USGS for 1985–2001 is  $0.15 \mu\text{g}/\text{L}$ . This value was selected for exposure estimation purposes because it was the most current and most representative of the national population. Using this value and an average adult water consumption rate of 1.4 L/d yields an estimated intake of  $0.2 \mu\text{g}/\text{day}$ . [This is from U.S. EPA ([1997](#)), but note that U.S. EPA ([2004](#)) indicates a mean per capita daily average total water ingestion from all sources of 1.233 L]. This is lower than the ATSDR ([1997c](#)) estimate water intake for the general population of 2–20  $\mu\text{g}/\text{day}$ . The use of the USGS survey to represent drinking water is uncertain in two ways. First, the USGS survey measured only groundwater and some drinking water supplies use surface water. Second, the USGS measured TCE levels at the well head, not the drinking water tap. Further discussion about the possible extent and magnitude of TCE exposure via drinking water is presented below.

According to ATSDR ([1997c](#)), TCE is the most frequently reported organic contaminant in ground water ([1997c](#)), and between 9 and 34% of the drinking water supply sources tested in the United States may have some TCE contamination. Approximately 90% of the 155,000 public drinking water systems<sup>1</sup> in the United States are ground water systems. The drinking water standard for TCE only applies to community water systems (CWSs) and approximately 78% of the 51,972 CWSs in the United States are ground water systems ([U.S. EPA, 2008a](#)). Although commonly detected in water supplies, the levels are generally low

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<sup>1</sup> 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. EPA further specifies three types of PWSs, including CWS—a PWS that supplies water to the same population year-round.

because, as discussed earlier, maximum contaminant level violations for TCE in public water supplies are relatively rare for any extended period ([U.S. EPA, 1998b](#)). The USGS ([2006](#)) survey found that the number of samples exceeding the maximum contaminant level (5 µg/L) was six at domestic wells (n = 2,400) and nine at public wells (n = 1,100). Private wells, however, are often not closely monitored and if located near TCE disposal/contamination sites where leaching occurs, may have undetected contamination levels. About 10% of Americans (27 million people) obtain water from sources other than public water systems, primarily private wells ([U.S. EPA, 1995b](#)). TCE is a common contaminant at Superfund sites. As of September, 2011, EPA's Superfund program has identified 761 sites with TCE as a contaminant of concern in groundwater, soil or both ([CERCLIS Public Access Database](#)). Studies have shown that many people live near these sites: 41 million people live <4 miles from one or more of the nation's NPL sites, and on average 3,325 people live within 1 mile of any given NPL site ([ATSDR, 1996b](#)).

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

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

|                | Consumption rate<br>(g/kg-d) | Consumption rate<br>(g/d) | Concentration in<br>food (µg/kg) | Intake<br>(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             |

<sup>a</sup>Consumption rates are per capita averages from EPA ([1997](#)).

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

#### 2.4.1.3. Dermal

TCE in bathing water and consumer products can result in dermal exposure. A modeling study has suggested that a significant fraction of the total dose associated with exposure to volatile organics in drinking water results from dermal absorption ([Brown et al., 1984](#)). EPA ([2004](#)) used a prediction model based on octanol-water partitioning and molecular weight to derive a dermal permeability coefficient for TCE in water of 0.012 cm/hour. EPA used this value to compute the dermally absorbed dose from a 35 minute shower and compared it to the dose from drinking 2 L of water at the same concentration. This comparison indicated that the

dermal dose would be 17% of the oral dose. Much higher dermal permeabilities were reported by Nakai et al. (1999) based on human skin in vitro testing. For dilute aqueous solutions of TCE, they measured a permeability coefficient of 0.12 cm/hour (26°C). Nakai et al. (1999) also measured a permeability coefficient of 0.018 cm/hour for tetrachloroethylene in water. Poet et al. (2000) measured dermal absorption of TCE in humans from both water and soil matrices. The absorbed dose was estimated by applying a physiologically based pharmacokinetic model to TCE levels in breath. The permeability coefficient was estimated to be 0.015 cm/hour for TCE in water and 0.007 cm/hour for TCE in soil (Poet et al., 2000).

#### 2.4.1.4. Exposure to TCE Related Compounds

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

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

| Chemical                  | Population   | Media | Range of estimated adult exposures (µg/d) | Range of adult doses (mg/kg-d)                | Data sources <sup>a</sup> |
|---------------------------|--------------|-------|---|---|---------------------------|
| Trichloroethylene         | General      | Air   | 11–33                                     | $1.57 \times 10^{-4}$ – $4.71 \times 10^{-4}$ | ATSDR (1997c)             |
|                           | General      | Water | 2–20 <sup>b</sup>                         | $2.86 \times 10^{-5}$ – $2.86 \times 10^{-4}$ | ATSDR (1997c)             |
|                           | Occupational | Air   | 2,232–9,489                               | $3.19 \times 10^{-2}$ – $1.36 \times 10^{-1}$ | ATSDR (1997c)             |
| Tetrachloroethylene       | General      | Air   | 80–200                                    | $1.14 \times 10^{-3}$ – $2.86 \times 10^{-3}$ | ATSDR (1997a)             |
|                           | General      | Water | 0.1–0.2                                   | $1.43 \times 10^{-6}$ – $2.86 \times 10^{-6}$ | ATSDR (1997a)             |
|                           | Occupational | Air   | 5,897–219,685                             | $8.43 \times 10^{-2}$ –3.14                   | ATSDR (1997a)             |
| 1,1,1-Trichloroethane     | General      | Air   | 10.8–108                                  | $1.54 \times 10^{-4}$ – $1.54 \times 10^{-3}$ | ATSDR (1995)              |
|                           | General      | Water | 0.38–4.2                                  | $5.5 \times 10^{-6}$ – $6.0 \times 10^{-5}$   | ATSDR (1995)              |
| 1,2-Dichloroethylene      | General      | Air   | 1–6                                       | $1.43 \times 10^{-5}$ – $8.57 \times 10^{-5}$ | ATSDR (1996a)             |
|                           | General      | Water | 2.2                                       | $3.14 \times 10^{-5}$                         | ATSDR (1996a)             |
| Cis-1,2-Dichloroethylene  | General      | Air   | 5.4                                       | $7.71 \times 10^{-5}$                         | HSDB (1996)               |
|                           | General      | Water | 0.5–5.4                                   | $7.14 \times 10^{-6}$ – $7.71 \times 10^{-5}$ | HSDB (1996)               |
| 1,1,1,2-Tetrachloroethane | General      | Air   | 142                                       | $2.03 \times 10^{-3}$                         | HSDB (2002)               |
| 1,1-Dichloroethane        | General      | Air   | 4   | $5.71 \times 10^{-5}$                         | ATSDR (1990)              |
|                           | General      | Water | 2.47–469.38                               | $3.53 \times 10^{-5}$ – $6.71 \times 10^{-3}$ | ATSDR (1990)              |
| Chloral                   | General      | Water | 0.02–36.4                                 | $2.86 \times 10^{-7}$ – $5.20 \times 10^{-4}$ | HSDB (1996)               |
| Monochloroacetic acid     | General      | Water | 2–2.4                                     | $2.86 \times 10^{-5}$ – $3.43 \times 10^{-5}$ | EPA (1994c)               |
| Dichloroacetic acid       | General      | Water | 10–266                                    | $1.43 \times 10^{-4}$ – $3.80 \times 10^{-3}$ | IARC (1995a)              |
| Trichloroacetic acid      | General      | Water | 8.56–322                                  | $1.22 \times 10^{-3}$ – $4.60 \times 10^{-3}$ | IARC (1995a)              |

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

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

## 2.4.2. Potentially Highly Exposed Populations

Some members of the general population may have elevated TCE exposures. ATSDR ([1997c](#)) 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-day and for infants under one year old it is 44 mL/kg-day) ([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, 1995a](#)). The major use of TCE is for metal cleaning or degreasing ([IARC, 1995a](#)). 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, 1995a](#)). Additionally, TCE is used in the manufacture of plastics, appliances, jewelry, plumbing fixtures, automobile, textiles, paper, and glass ([IARC, 1995a](#)).

Table 2-14 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 TCE 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](#)).

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

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

<sup>a</sup>A mixture of straight and branched chain paraffins (48%), naphthenes (38%), and aromatic hydrocarbons (14%).

Sources: Stewart and Dosemeci (2005); Bakke et al. (2007).

Occupational exposure to TCE has been assessed in a number of epidemiologic and industrial hygiene studies. Bakke et al. (2007) estimated that the arithmetic mean of TCE occupational exposures across all industries and decades (mostly 1950s, 1970s, and 1980s) was 38.2 ppm (210 mg/m<sup>3</sup>). They also reported that the highest personal and area air levels were found in vapor degreasing operations (arithmetic mean of 44.6 ppm or 240 mg/m<sup>3</sup>). Hein et al. (2010) developed and evaluated statistical models to estimate the intensity of occupational exposure to TCE (and other solvents) using a database of air measurement data and associated exposure determinants. The measurement database was compiled from the published literature and National Institute for Occupational Safety and Health (NIOSH) reports from 1940 to 1998 (*n* = 484) and were split between personal (47%) and area (53%) measurements. The predicted arithmetic mean exposure intensity levels for the evaluated exposure scenarios ranged from 0.21 to 3,700 ppm (1.1–20,000 mg/m<sup>3</sup>) with a median of 30 ppm (160 mg/m<sup>3</sup>). Landrigan et al. (1987) used air and biomonitoring techniques to quantify the exposure of degreasing workers who worked around a heated, open bath of TRI. Exposures were found to be between 22 and 66 ppm (117–357 mg/m<sup>3</sup>) on average, with short-term peaks between 76 and 370 ppm (413–2,000 mg/m<sup>3</sup>). High peak exposures have also been reported for cardboard workers who were involved with degreasing using a heated and open process (Henschler et al., 1995). Lacking industrial hygiene data and making some assumptions about plant environment and TCE usage, Cherrie et al. (2001) estimated that cardboard workers at a plant in Germany had peak exposures in the range of 200–4,000 ppm (1,100–22,000 mg/m<sup>3</sup>) and long-term average exposures of 10–225 ppm (54–1,200 mg/m<sup>3</sup>). ATSDR (1997c) reports that the majority of published worker exposure data show time-weighted average concentrations ranging from <50 ppm–100 ppm (<270–540 mg/m<sup>3</sup>). NIOSH conducted a survey of various industries from

1981 to 1983 and estimated that approximately 401,000 U.S. employees in 23,225 plants in the United States were potentially exposed to TCE during this timeframe ([ATSDR, 1997c](#); [IARC, 1995a](#)). Occupational exposure to TCE has likely declined since the 1950s and 1960s due to decreased usage, better release controls, and improvements in worker protection. Reductions in TCE use are illustrated in Table 2-14, which shows that by about 1980, common degreasing operations had substituted other solvents for TCE.

#### 2.4.2.2. Consumer Exposure

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

#### 2.4.3. Exposure Standards

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

**Table 2-15. TCE standards**

| Standard   | Value  | Reference                   |
|--|--|-----------------------------|
| OSHA Permissible Exposure Limit: Table Z-2 8-hr time-weighted average.   | 100 ppm<br>(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-hr shift except as allowed in the maximum peak standard below). | 200 ppm<br>(1,076 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-hr shift. Maximum Duration: 5 minutes in any 2 hrs.                           | 300 ppm<br>(1,614 mg/m <sup>3</sup> )                    | 29 CFR 1910.1000 (7/1/2000) |
| Maximum contaminant level under the Safe Drinking Water Act.   | 5 ppb (5 µg/L)   | 40 CFR 141.161              |
| FDA Tolerances for<br>decaffeinated ground coffee<br>decaffeinated soluble (instant) coffee<br>extract spice oleoresins.   | 25 ppm (25 µg/g)<br>10 ppm (10 µg/g)<br>30 ppm (30 µg/g) | 21 CFR 173.290 (4/1/2000)   |

OSHA = Occupational Safety and Health Administration

## 2.5. EXPOSURE SUMMARY

TCE is a volatile compound with moderate water solubility. Most TCE produced today is used for metal degreasing. The highest environmental releases are to the air. Ambient air monitoring data suggests that levels have remained fairly constant since 1999 at about 0.3 µg/m<sup>3</sup>. Indoor levels are commonly three or more times higher than outdoor levels due to releases from

building materials and consumer products. TCE is among the most common groundwater contaminants and the median level based on a large survey by USGS for 1985–2001 is 0.15 µg/L. It has also been detected in a wide variety of foods in the 1–100 µg/kg range. None of the environmental sampling has been done using statistically based national surveys. However, a substantial amount of air and groundwater data have been collected allowing reasonably well supported estimates of typical daily intakes by the general population: inhalation—13 µg/day and water ingestion—0.2 µg/day. The limited food data suggests an intake of about 5 µg/day, but this must be considered preliminary.

Much higher exposures have occurred to various occupational groups. For example, past studies of aircraft workers have shown short term peak exposures in the hundreds of ppm (>540,000 µg/m<sup>3</sup>) and long term exposures in the low tens of ppm (>54,000 µg/m<sup>3</sup>). Occupational exposures have likely decreased in recent years due to better release controls and improvements in worker protection.

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