Chapter 1
History of TCE

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Abstract The use of trichloroethylene (TCE) spans a period beginning in the early twentieth century and continuing to the present day. Although the largest use of TCE in terms of volume was in the degreasing of metals, it was also used in dry cleaning, textile processing, food processing, medical applications, chemical production, and a variety of consumer products. The use and production of TCE evolved significantly over time in response to market conditions, historical events, economic climate, technology development, environmental regulations, toxicity concerns, and the availability of competing products. The spillage and disposal of TCE resulted in the contamination of countless groundwater supply wells, the cleanup of which will likely continue for decades to come.

Keywords Trichloroethylene • History • Trichloroethene • TCE

1.1   Introduction

Trichloroethylene (TCE, C_2HCl_3), also known by its IUPAC[1] name of trichloroethene and a host of other chemical and trade names (see Table 1.1), has been used for a variety of industrial, commercial, medical, and consumer applications. Its widespread use, particularly in the mid-twentieth century, stemmed from its powerful solvent action on fats, greases, oils, resins, waxes, and a variety of other natural and synthetic substances. The use of TCE as an industrial metal cleaning agent,

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[1] IUPAC, the International Union of Pure and Applied Chemistry, is recognized as the world authority on chemical nomenclature.

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Table 1.1 Synonyms for trichloroethylene (Doherty 2000; IARC 1997; Barbalace 2013)

Chemical names:
1,1,2-trichloroethylene
1,2,2-trichloroethylene
1,1-dichloro-2-chloroethylene
1-chloro-2,2-dichloroethylene
Acetylene trichloride
Ethinyl trichloride
Trichloroethene
Ethylene trichloride
Trade names (manufacturer names in italics):
Algylen
Alk-Tri *(Dow Chemical)*
Anamenth
Benzinol
Blacosolv (industrial grade)*(G.S. Blakeslee)*, Blancosolv
Cecolene
Chlorylen, Chlorilen, Chlorylea
Circolsolv
Crawhaspol
Densinfluat
Dow-Tri *(Dow Chemical)*
Dukeron
Ethyl Trichloroethylene (industrial grade)
Ex-Tri *(Dow Chemical)*
Fleck-Flip, Flock Flip
Fluate
Gemalgene, Germalgene
Hi-Tri *(Dow Chemical)*
Lanadin
Lethurin
Narcogen, Narkogen
Narcosoid, Narkosoid
NCI-C04546
Neu-Tri *(Dow Chemical)*
Nialk, Nialk Trichlor (*Hooker Chemical*)
Perm-A-Clor (*Hooker-Detrex, Inc.*)
Petzinol
Philex, Phillex (industrial grade)
Stauffer Trichloroethylene *(Stauffer Chemical)*
Threthylen, Threthylene, Trethylene
Triad, Triad-E *(Hooker-Detrex, Inc.)*
Tri, Trial, Triasol
Trichlooretheen, Trichloorethyleen
Trichloraethen, Trichloraethylen
Trichlor Type 113/114/115/122 (industrial grade)
Trichloran, Trichloren
Tricloretene, Tricloroetilene
Triclene, Tri-Clene (*DuPont, Diamond Shamrock*)

Table 1.1   (continued)

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| Trielina, Trielene, Trielin, Trieline |
| Triklone (industrial grade) |
| Trilene, Trilen, Triline (anesthetic grade) |
| Trimar |
| Triol |
| Tri-Paint Grade (industrial grade) |
| Tri-Plus, Tri-Plus M |
| Trisan |
| Trivec |
| Tromex |
| Un 1710 |
| Vapoclean |
| Vapoclor |
| Vestrol |
| Vitran |
| Westrosol |

primarily in the vapor degreasing process, was undoubtedly its largest use in terms of quantity. However, other important uses existed. This chapter explores major uses of TCE and how they evolved over time, and briefly discusses TCE's role as an environmental contaminant.

TCE was first prepared in 1864 by Dr. E. Fischer of Neustrelitz, Germany (Fischer 1864). However, TCE was not utilized for commercial or industrial purposes until over 40 years after Dr. Fischer's work. Potential commercial applications in dry cleaning, textiles, varnishes, and as an extraction agent for fats led to the construction of production facilities in Yugoslavia in 1908 (Gerhartz 1986) and Germany in 1910 (Mellan 1957). In the United States, limited production by Dow Chemical and the Carbide and Carbon Chemicals Corporation (a predecessor of Union Carbide) began in 1921. The Roessler & Hasslacher Company (a predecessor of DuPont) began production in Niagara Falls, New York in 1925 (Doherty 2000).

TCE was produced by a variety of methods that evolved over time. The primary production process, developed in Austria in approximately 1905, involved the chlorination of acetylene to produce 1,1,2,2-tetrachloroethane, which was then dehydrochlorinated to produce TCE (Hardie 1964). During the 1970s, the rising price of acetylene gradually rendered this method uncompetitive, and the last major manufacturing plant in the United States (US) that utilized the acetylene process was closed by Hooker Chemical in 1978. More recent widely-used production processes include high-temperature chlorination of ethylene or 1,2-dichloroethane, and the oxychlorination of ethylene or C_2 chlorinated hydrocarbons (Mertens 1991). All three of these major production methods yield tetrachloroethylene (PCE) in addition to TCE.

Pure TCE slowly auto-oxidizes in the presence of air, and rapidly degrades when in contact with aluminum. Beginning in approximately the mid-1930s, commercial grades of TCE included low concentrations (typically 0.1–0.5 %) of stabilizing chemicals to counteract the deleterious effects of acids, certain metals, oxygen, heat, and/or light. Stabilizers used for TCE generally fall into one of three classes:
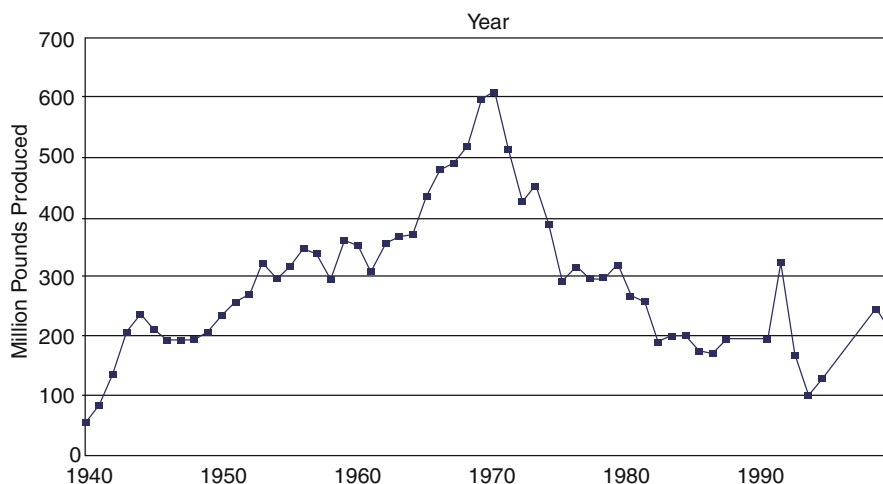
Fig. 1.1 US production of TCE (Doherty 2000; Lee et al. 2003; Leppart 1945)

acid acceptors to neutralize hydrogen chloride, metal stabilizers to form complexes with metal salts, and antioxidants to retard formation of oxidation products. Acid acceptors used prior to 1954 commonly included trimethylamine, triethylamine, and diisopropylamine, which were of limited effectiveness because they were consumed in the neutralization process. The introduction of a neutral, pyrrole-based stabilizer formulation by DuPont in the mid-1950s began the transition away from amine-based formulations. Other chemicals used as TCE stabilizers included alcohols, esters, ethers, substituted phenols and epoxides (primarily epichlorohydrin and butylene oxide). TCE used as an analgesic contained 0.008–0.012 % thymol as an anti-microbial agent. Dyes such as waxoline blue were sometimes added to help distinguish TCE from chloroform (Aviado et al 1976; Doherty 2000).

Production volumes of TCE in the United States are shown on Fig. 1.1. TCE production reached a short-term peak in the mid-1940s to meet World War II demands for production and cleaning of military equipment. Similar to nearly all industrial materials, TCE's production and distribution were strictly controlled by the United States government during the World War II years to allow military and, to a lesser extent, essential civilian demands to be met. The evolution of the various US government orders that restricted the use of TCE and allocated available supplies are described by Doherty (2012).

After World War II, TCE production continued to increase, primarily in response to its use in metal degreasing. Civilian and Korean War-related demand led to a December 1950 US ban on hoarding of TCE and 54 other scarce materials (J City Post Tribune 1950). Although TCE producers significantly expanded production capacity in the post-war years, supplies remained relatively scarce until the economic slowdown of the late 1950s. During the 1960s, decreased imports, high demand for vapor degreasing solvent, and military demand associated with the Vietnam War caused TCE's production in the US to increase significantly, reaching a peak in 1970 when approximately 600 million pounds were produced (US Tariff Comm 1971).

One of the first environmental regulations to significantly affect demand for TCE was California's Rule 66, a law intended to control the use of smog-promoting chemicals. Enacted in August 1966, Rule 66 caused many TCE users in California to switch to alternative solvents such as PCE or 1,1,1-trichloroethane (C&EN 1969). On a national level, the 1970 Clean Air Act regulated TCE as an air pollutant and set emission limits on users in ozone non-attainment areas. In March 1975, the National Cancer Institute (NCI) released its finding that TCE caused cancerous tumor growth in mice livers (NCI 1976). In 1976, the US Environmental Protection Agency (EPA) added TCE to its Hazardous Substances List. These and other factors (including the shutdown of TCE plants utilizing the acetylene process) led to significant reductions in production and use of TCE throughout the 1970s.

While environmental regulations contributed to a continued decline in TCE production and use in the 1980s, they resulted in a minor resurgence in use in the 1990s. The 1990 Clean Air Act Amendments and the 1990 amendments to the Montreal Protocol set dates by which the use of 1,1,1-trichloroethane, 1,1,2-trichloro-1,2,2-trifluoroethane, and carbon tetrachloride (among other chemicals) would be severely restricted. Many users of these chemicals turned to TCE as a substitute, contributing to a reported 10 % annual increase in TCE consumption in the US between 1993 and 1996 (Leder 1999).

Between 1996 and 2012, annual US exports of TCE ranged from a low of 36.8 million pounds in 2005 to a high of 84.4 million pounds in 1998. In 2011 and 2012, over 50 million pounds were exported each year. Major importers were Korea, the Netherlands, and China, each of whom imported over 100 million pounds from the US over the 17-year period (USITC 2013). Global consumption of TCE in 2011 was estimated at 945 million pounds, of which 255 million pounds was in the US (Glauser and Funda 2012).

1.2 TCE Uses

1.2.1 Dry Cleaning and Textile Processing

TCE, along with carbon tetrachloride, was one of the first chlorinated solvents to be used in dry cleaning as a substitute for petroleum-based cleaners. While the chlorinated solvents were historically more expensive than petroleum cleaners, they offered two major advantages: they had essentially no risk of fire or explosion, and they did not leave a residual odor on dry-cleaned clothing. TCE's use in dry cleaning began in approximately 1930, and increased throughout the decade. However, dry cleaning use decreased after it was found to cause bleeding of dyes on cellulose acetate fibers (Chem Wk 1953).

TCE formulations prepared for use in the textile industry were available in England as of 1912 (Chem Tr J Chem Eng 1912). TCE was used to scour wool, cotton, and other fabrics, and as a solvent in dyeing and finishing operations.

In the years following World War II, TCE was used to remove waxes and oils from natural and artificial fabrics in preparation for desizing, bleaching, dyeing, printing and finishing (Hardie 1964). As of the early 1990s, it was in use as a carrier solvent for spotting fluids, and in waterless dyeing and finishing operations (Mertens 1991). The 1990 restrictions on the use of 1,1,1-trichloroethane prompted the textile industry to use TCE to remove oil and grease stains from fabrics (Mirza et al. 2000).

1.2.2   Metal Cleaning and Degreasing

TCE's predominant use was as a degreasing agent, an application for which the chemical was remarkably well-suited due to its solvent action, noncorrosivity, rapid evaporation, lack of flammability, and ease of recycling. TCE was used for this purpose by a variety of industries, including electronics, defense, aerospace, aviation, rail, shipbuilding, and automotive, among others. Among the many hundreds of TCE's cleaning applications was the flushing of liquid oxygen tanks, liquid hydrogen tanks, and associated piping systems by the aerospace industry (PPG Ind 1999).

Although TCE was utilized for so-called "cold cleaning" (i.e., cleaning using room-temperature TCE), its major metal cleaning use was in vapor degreasing machines, the use of which dates back to the 1920s. By the mid-1930s, vapor degreasing technology had evolved to the point where these machines were used by many leading manufacturers of metal products (Davidson 1938). By the 1940s, the largest use of TCE was in the vapor degreasing of metals (Kirk and Othmer 1949). As of 1952, 92 % of TCE produced in the US was used in vapor degreasing (Chem Wk 1953). This percentage remained relatively constant until the mid-1970s, when it dropped to approximately 80 % due to the increased use of the less toxic 1,1,1-trichloroethane in vapor degreasers (Doherty 2000).

In its simplest form, a vapor degreaser consists of a metal rectangular container with an open top. A shallow layer of liquid TCE[2] at the bottom of the container is heated, causing TCE vapors (which are heavier than air) to rise into the middle and upper portions of the container. Near the top of the container are cooling coils that cause TCE vapors in the upper portions to condense, thereby inhibiting their escape from the container. Objects to be cleaned are placed in the TCE vapor zone that exists above the liquid TCE and below the cooling coils. Because the objects are initially at a lower temperature than the TCE vapors, TCE condenses on the objects, and dissolves oils, greases, and other soluble materials that may be present. The condensed TCE, along with dissolved materials, drips off the objects into the liquid layer below. When the objects reach the temperature of the vapors, condensation

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[2] The most widely used vapor degreasing solvents other than TCE were PCE and 1,1,1-trichloroethane. The latter compound did not see significant use in vapor degreasing until roughly the mid-1960s due to difficulties with stabilization.

ceases. When the objects are removed from the degreaser, residual TCE quickly evaporates, leaving the work clean, dry and ready for further processing, such as painting, welding, inspection, or shipment.

Oils, greases, and other materials removed in the vapor degreasing process accumulated in the TCE reservoir at the bottom of the degreaser. As the concentrations of these impurities increased, the effectiveness of the solvent decreased. Therefore the TCE needed to be periodically replaced with fresh solvent, or distilled to remove impurities. The spent TCE and accumulated materials (or the still bottoms left after distillation) needed to be removed for recycling or disposal. Historical disposal practices of these wastes led to the introduction of TCE into soil and groundwater, as discussed further below.

Variations on the typical vapor degreasing process included the addition of steps where objects were immersed in liquid solvent, or subjected to a solvent spray. Some models included a distillation unit to recover used solvent. Because the vapor degreasing process involved exposure to metals at elevated temperatures, vapor degreasing grades of TCE included stabilizers to help prevent solvent degradation.

TCE, as well as other solvents, were used in ultrasonic cleaning machines that combined the solvent power of TCE with the agitation caused by high-frequency sound waves. These machines typically employed solvent in liquid rather than vapor form, and were best-suited to cleaning small parts with openings or recesses that were difficult to clean by other methods. The use of TCE in ultrasonic cleaners dates back to approximately 1953 (Business Week 1953).

1.2.3 Other Industrial, Commercial and Military Uses

In addition to its primary use as a metal cleaning agent, TCE was also used to a lesser degree as a refrigerant; a heat transfer medium; a cleaner for optical lenses and film; a solvent for fats, waxes, resins, oils, perfumes, greases, rubber, paints, and varnishes; and an ingredient in printing inks, paint strippers, lacquers, lubricants, pesticides, paints, adhesives, and rust preventors (Hardie 1964; Huff 1971; Doherty 2000).

During World War I, TCE was used extensively in Germany as a substitute for benzene and alcohol in the dissolution of fats. Four cases of poisoning at a German munitions plant were reported by Plessner in 1916. Exposure to TCE used as a substitute for carbon tetrachloride in the preparation of brake linings was cited as the cause of death of a New Jersey worker in 1923 (Hamilton 1925).

Carbon tetrachloride-based fire extinguishers, used for fighting liquid and electrical fires throughout the early-to-mid-twentieth century, could be utilized in conditions below carbon tetrachloride's −9 °F (−23 °C) freezing point by adding TCE. During World War II, the US Army Air Force recommended that TCE be added to carbon tetrachloride fire extinguishers to be used in cold conditions (HQ AAF 1944).

TCE was used by the chemical industry in the production of polyvinyl chloride, chloroacetic acid, hydrofluorocarbons, pharmaceuticals, insecticides, fungicides, fire retardants, fertilizer, and synthetic rubber (Leppart 1945; USEPA 1979; Doherty 2000). One of the major current uses for TCE is as a feedstock in the production of refrigerants (ICIS 2010).

1.2.4   Medical Uses

The use of TCE in the medical field included use as a general anesthetic and an analgesic in dental extractions, childbirth and other short surgical procedures (NIOSH 1975). Veterinary applications included use as an anesthetic for dogs, pigs, and cats, and as a disinfectant and detergent for surgical instruments and minor wounds (Huff 1971).

Reports of TCE's use in medicine date back to 1915, when it was used on a trial basis in Europe as an inhalant for the treatment of trigeminal neuralgia (Oppenheim 1915, cited in Parkhouse 1965). Reports of similar trials in the US date to 1928 (Oljenick 1928, cited in Parkhouse 1965). Due to the limited success of these trials and the finding that TCE had no specific effect on the trigeminal nerve, TCE was not widely used in the treatment of trigeminal neuralgia.

The use of TCE to anesthetize dogs was reported by Jackson in 1933 (Jackson 1934). In 1934, a pharmaceutical grade of TCE became available in England, and was recommended for cleaning wounds and burns (Hardie 1964). In 1935, Striker et al. reported on the use of TCE as an anesthetic and analgesic in over 300 cases (Striker 1935). In 1936, the Council on Pharmacy and Chemistry of the American Medical Association concluded that "the available evidence does not justify the acceptance of trichloroethylene for use as a general anesthetic" (JAMA 1936). However, the wartime need for a non-flammable anesthetic led to additional trials, and TCE became widely used for this purpose during the World War II years.

The use of TCE as an anesthetic was generally more common in Europe than in the US (Bundesen 1953). However, an estimated 35,000 l of TCE were used as an anesthetic and analgesic in the US in 1958 (Huff 1971). TCE's use as a general inhalational anesthetic decreased after the introduction of halothane in 1956 but it continued to be used throughout the 1960s (Aviado et al 1976). By 1975, it was estimated that no more than 60,000 patients per year were anesthetized using TCE (Seltzer 1975).

TCE was found to be an effective analgesic during proctoscopic examinations, for post-operative pain relief, for narcohypnosis, for angina pectoris, and for pregnant women in early stages of labor (Aviado et al 1976). TCE was used as an anesthetic during the birth of Queen Elizabeth's first child (Stafford 1952). Methods for self-administration of TCE by expectant mothers in labor were in use in the mid-1950s (Miles 1954). The widespread use of TCE in obstetrical analgesia was described by Parkhouse (1965), who described it as "the most convenient

form of inhalation analgesia in terms of apparatus; it is certainly more effective that nitrous oxide/air, and involves less danger of maternal and fetal hypoxia."

1.2.5   Food Processing

TCE was used in the food processing industry primarily for extraction of fats, oils, and other substances from fish meal, meat meal, oil-containing seeds, soybeans, and coffee beans (Hardie 1964). Additional applications as of the mid-1950s included the extraction and purification of olive, maize, linseed, and other edible oils (Mellan 1957). It was also used as a fumigant for grains and other foodstuffs (OPM 1941), and in the preservation of eggs and fruit. The use of TCE for fat extraction dates back to at least 1916, when cattle poisonings were attributed to the use of TCE in defatting soybean oil meal animal feeds (Huff 1971). Extensive losses of cattle in Europe between 1923 and 1925 were attributed to the same source. Nevertheless, by 1927, "large and ever-increasing quantities" of TCE were being used by the food processing industry as an extraction solvent for natural fats and palm, coconut and soybean oils (Mertens 1991; Ind Chem 1927). In the US, the attribution of hemorrhagic diseases in cattle fed with TCE-treated soybean meal led to the voluntary withdrawal of the product in 1952 (Chem Wk 1953; Huff 1971).

Other reported uses of TCE included hop extraction and removal of oleoresins from spices (Mertens 1991; Seltzer 1975). TCE was one of a number of chemicals historically used to extract caffeine from coffee beans to produce decaffeinated coffee. As of 1975, the US Food and Drug Administration (FDA) limited TCE concentrations to 10 parts per million (ppm) in decaffeinated instant coffee, 25 ppm in decaffeinated ground coffee, and 30 ppm in spice oleoresins (Seltzer 1975). After NCI released its finding that TCE caused cancerous tumor growth in mice, the General Foods Corporation announced in July 1975 that it would substitute methylene chloride for TCE in the production of its decaffeinated coffee brands (C&EN 1975).

In 1977, the US FDA proposed a ban on the use of TCE in direct or indirect food production, cosmetics, and drug products (Mertens 1991; Conlon 1976). However, the ban was not enacted, and the 1975 residual concentration limits for TCE in decaffeinated coffee and spice oleoresins remain in effect (21 CFR 173.290 2012). The current allowable TCE residual in modified hop extract used in beer is set by the FDA at 150 ppm (21 CFR 172.560 2012).

1.2.6   Consumer Products

TCE was used in a wide variety of consumer products, including cleaning fluids, disinfectants, deodorizers, and adhesives. Huff (1971) provided a table of 26 commercially-available products that contained TCE, including spot remover,

rug cleaner, air freshener, tree wound healer, chimney sweep cleaner, and false eyelash cleaner. Use as a wig cleaner, typewriter correction fluid, septic system cleaner, and mildew preventer has also been reported (Aviado et al 1976; US DHHS 1997; Kaplan 1983).

TCE was an ingredient in one formulation of Carbona, a widely-used household spot remover. Carbona, along with other cleaning and adhesive products that contained TCE, were commonly misused as narcotics during the 1950s, 1960s, and early 1970s by inhaling the vapors in an enclosed space. The resulting euphoric effects were often followed by nausea, vomiting, and in some cases, death (Huff 1971).

1.3   Environmental Impacts and Regulatory Development

The widespread use of TCE in degreasing coupled with the disposal practices prevalent during most of the twentieth century resulted in substantial releases of TCE to the environment. According to the Agency for Toxic Substances & Disease Registry (ATSDR), TCE is one of the most common contaminants found at Federal Superfund sites, having been detected at 852 of 1,430 sites as of 1997 (US DHHS 1997). The presence of TCE in soil, groundwater, and soil vapor at impacted locations has in some cases resulted in prolonged human exposure through both inhalation and ingestion routes. Due to TCE's relatively high persistence in the subsurface environment, it will likely continue to be present in these media (particularly groundwater) for decades to come.

Early instances of TCE contamination of groundwater were reported in the Reading, England area by Lyne and McLachlan (1949). Their short article described two cases of TCE contamination in wells near areas where TCE was released to the environment, and correctly noted that "it is evident that contamination by compounds of this nature is likely to be very persistent." A 1950 summary of Lyne and McLachlan's article in the American Chemical Society's *Chemical Abstracts* noted that "It often happens that wells near factories which use large quantities of C_2HCl_3 are rendered unfit for drinking by contamination by this liquid" (Hall 1950).

In addition to regulations mentioned in this chapter's Introduction (Rule 66 and the 1970 Clean Air Act), many other regulations affected the use of TCE. On October 21, 1976, the Resource Conservation and Recovery Act (RCRA) was enacted. EPA's press release announcing the act noted that "the contamination of groundwaters by substances leaching from disposal sites is a primary concern" (USEPA 1976). The original regulations promulgated under RCRA in 1980 included TCE in waste categories F001, F002 and U228. A fourth category (D040) was added by the Hazardous and Solid Waste Amendments of 1984.

TCE was one of the original 65 priority pollutants included in the 1977 Clean Water Act, which amended the 1972 Water Pollution Control Act to provide better control of discharges of toxic chemicals (Arbuckle et al 1991). Reportable

quantities for spills of TCE and a variety of other chemicals were established under the 1980 Comprehensive Environmental Response, Compensation & Liability Act (CERCLA), which created the "Superfund" for the cleanup of the most serious hazardous waste sites, the majority of which were impacted to some degree by TCE.

To comply with the 1974 Safe Drinking Water Act's requirement to establish regulations for public water supplies, EPA proposed non-enforceable Maximum Contaminant Level Goals (MCLGs) for TCE and seven other chemicals on June 12, 1984 (USEPA 1984). Enforceable Maximum Contaminant Levels (MCLs) for the eight chemicals including TCE were proposed on November 13, 1985, and became effective January 9, 1989 (USEPA 1985 and USEPA 1987). The MCL for TCE was set at 5 parts per billion (ppb), and remains at that level to this day.

TCE contamination of groundwater has led to the closure of, or the need to provide treatment for, countless public and private water supply wells. Although a few notable examples of TCE contamination in the US are discussed herein, the scope of the problem is so broad that it is impractical to provide a comprehensive summary. While the number of Superfund sites impacted by TCE releases numbered less than 1,000 as of 1997, it is likely that the number of non-Superfund sites in the US (i.e., those regulated under state programs) far exceeds that number.

TCE was the primary contaminant in Wells G and H in Woburn, Massachusetts, the story of which was documented in the book (Harr 1995) and 1998 film "A Civil Action." A cluster of childhood leukemia cases, along with complaints of chemical tastes and odors from tap water, prompted residents to unsuccessfully lobby for shutdown of the Wells G and H in 1969. Ten years later, after 184 drums of polyurethane resin waste were found and removed from a nearby vacant lot, Massachusetts officials tested the wells and detected TCE in wells G and H at 267 and 183 ppb, respectively (Harr 1995). The wells were shut down in 1979, and the cleanup of the site is currently in its eighteenth year (USEPA 2013a).

In 1979, groundwater contamination by TCE, and, to a lesser degree, PCE and other chemicals, was discovered in wells in California's San Gabriel valley. The state's Department of Health Services (DHS) initiated a sampling program that led to the identification of 59 contaminated wells and, beginning in 1984, the inclusion of four locations on the Superfund National Priorities List (NPL). Cleanup at these Superfund sites is on-going and, based on the extent and difficulty of removing TCE from contaminated aquifers, is likely to continue for decades (USEPA 2011a and USEPA 2013b).

In the following year, DHS initiated a sampling program in the San Fernando Valley, a nearby area that is similar in terms of both geology and a history of heavy industrial usage. Large areas of the valley's aquifer were found to be contaminated, primarily with TCE and PCE. As a result, numerous water supply wells were taken out of service, and water was purchased from the Metropolitan Water District of Southern California. In 1986, four locations within the valley were declared Superfund sites (USEPA 2013b).

Beginning in 1980, testing of water supplies at the US Marine's Camp Lejeune in North Carolina for trihalomethanes (by-products of chlorination of water) indicated the presence of high levels of halogenated hydrocarbons (Barrett 2010).

By 1982, PCE, TCE, benzene and lesser concentrations of other chemicals had been identified, and the first of the impacted water supply wells was shut down in 1984. Cleanup activities are on-going (USEPA 2013c).

In recent years, increased attention has been focused on the impact of TCE-contaminated groundwater on indoor air. Migration of TCE vapors into buildings and subsurface structures has been noted at many sites impacted by TCE and other volatile organic compounds.

While the historic volume of TCE released to ambient (outdoor) air undoubtedly exceeded that released to soil and groundwater, TCE's half life in air is approximately 7 days, far shorter than typical half-lives in subsurface environments. According to the Toxics Release Inventory database (USEPA 2011a), TCE releases to air were 2.7 million pounds in 2011, down from a reported 9.8 million pounds in 2000 and over 40 million pounds in 1990. To a large extent these values reflect a decades-long trend of decreased TCE use by industry.

In September 2011, after nearly 25 years of evaluation and debate, EPA formally revised toxicity factors for TCE in response to data that indicated that previous factors underestimated risks to human health (USEPA 2011b). The revised toxicity factors may lead to a lowering of cleanup levels at TCE sites and a lowering of TCE's drinking water standard. The future effect of EPA's revisions may be even further reductions in the use of what once was a widely-used and readily available industrial, commercial, and household chemical.

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