ES&T FEATURES

Banning trichloroethylene: Responsible reaction or overkill?

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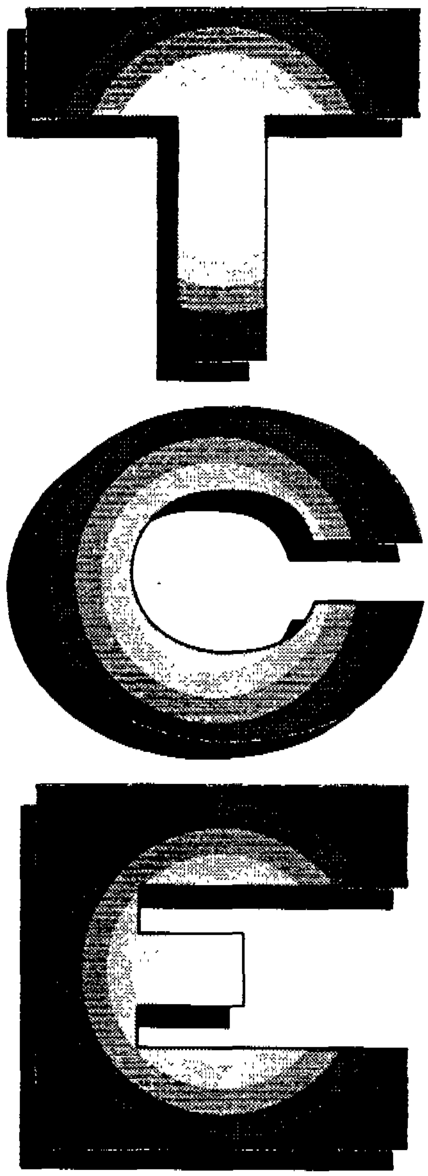

Trichloroethylene (TCE) has been used since the 1940s. Since the late 1970s TCE has been the subject of environmental and public health concern and controversy. Common methods used by industry and government facilities for the disposal of chlorinated solvents prior to 1980 have resulted in widespread groundwater contamination. This paper provides background information on the use, disposal, fate, and impact of TCE from the 1940s to the present.

From useful to hazardous substance

TCE has been used in the United States for many years as an excellent degreasing agent, a popular dry cleaning solvent, an extraction agent in decaffeinating coffee, a general anesthetic in medicine and dentistry, and in numerous other ways *(1)*. Its uses were severely curtailed in 1976, however, when a study by the National Cancer Institute provided evidence that TCE, in very high experimental dosages, caused tumor growths in a sensitive species of mouse *(2)*. It is interesting to note that subsequent studies by other researchers have failed to reproduce the carcinogenic response to TCE from any species of test animal *(3, 4)*. Recent epidemiological studies in Michigan and California have failed to implicate TCE as a cause of cancer in humans *(5, 6)*.

Although no direct evidence existed in the past, or even now, that the ingestion of small amounts of TCE elicits a carcinogenic response in humans, the scientific community and environmental regulatory agencies concluded in 1976 that TCE was a "suspected carcinogen" and should be banned. In 1976, TCE was included on the ever-expanding EPA list of hazardous substances.

In recent years, TCE has been discovered in groundwater used for human consumption throughout the United States. It has become the subject of extensive governmental regulation and a target chemical in perhaps hundreds of environmental litigations. However, little has been presented in the technical literature regarding the origin and development of the environmental and public health problems created by this once-beneficial substance.

Properties of TCE

An understanding of the origin and fate of TCE in the environment requires some background knowledge of the properties and characteristics of this controversial substance. Trichloroethylene ($Cl_2C{=}CHCl$) is a synthetic, chlorinated organic chemical that fulfills all requirements for the ideal degreasing solvent *(1, 7*; see box).

TCE is only slightly soluble in water (about 1100 ppm at 77 °F) and forms an azeotrope with water, resulting in a mixture with a lower boiling point and vapor density. It is considered to be a "highly volatile" compound and favors environmental partitioning to the air rather than water *(8)*. TCE is destroyed by photooxidation in the atmosphere, with a half-life of about one day.

TCE, like other chloroethenes, transforms through reductive dehalogenation very slowly in the soil or groundwater environment. Bouwer and McCarty noted that TCE can be transformed slowly under methanogenic conditions at low concentration *(9)* and also very slowly under denitrification conditions *(10)*. They noted that no degradation occurs under aerobic conditions. These observations indicate why TCE persists in soil and groundwater for a considerable time.

Some other chlorinated organic solvents of current concern are perchlorethylene (PCE), trichloroethane (TCA), carbon tetrachloride, and methylene chloride.

Sources of TCE contamination

Over the years, TCE has been discharged to the nation's surface waters and groundwaters by industry, commerce, and individual consumers. About 90% of the TCE produced in 1974 was used in industrial degreasing. EPA estimates that in 1974 approximately 310,200 tons of waste solvents were produced by degreasing opera-

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tions *(11)*. Meanwhile, lesser amounts of TCE were being used and discarded by dry cleaners, septic tank cleaners, and other operators of cleaning establishments that used chlorinated solvents.

Until recently, many commonly used consumer products included TCE. Some of these made their way into the environment by way of septic tanks, the sewer, or municipal landfills. Among these products were drain and pipe cleaners, shoe polish, spot removers, paint removers, upholstery cleaners, adhesives, and septic tank cleaners *(12, 13)*.

Discovery of TCE in groundwater

TCE was discovered in the fall of 1979 in a groundwater aquifer in the vicinity of Sacramento, California *(14)*. Although this was one of the earliest reported discoveries of TCE contamination of groundwater, it does not mean that the contamination there, or elsewhere, had just occurred. In fact, it was subsequently found that this aquifer had been contaminated with TCE for several years, perhaps since as early as the 1950s, but the problem had defied discovery.

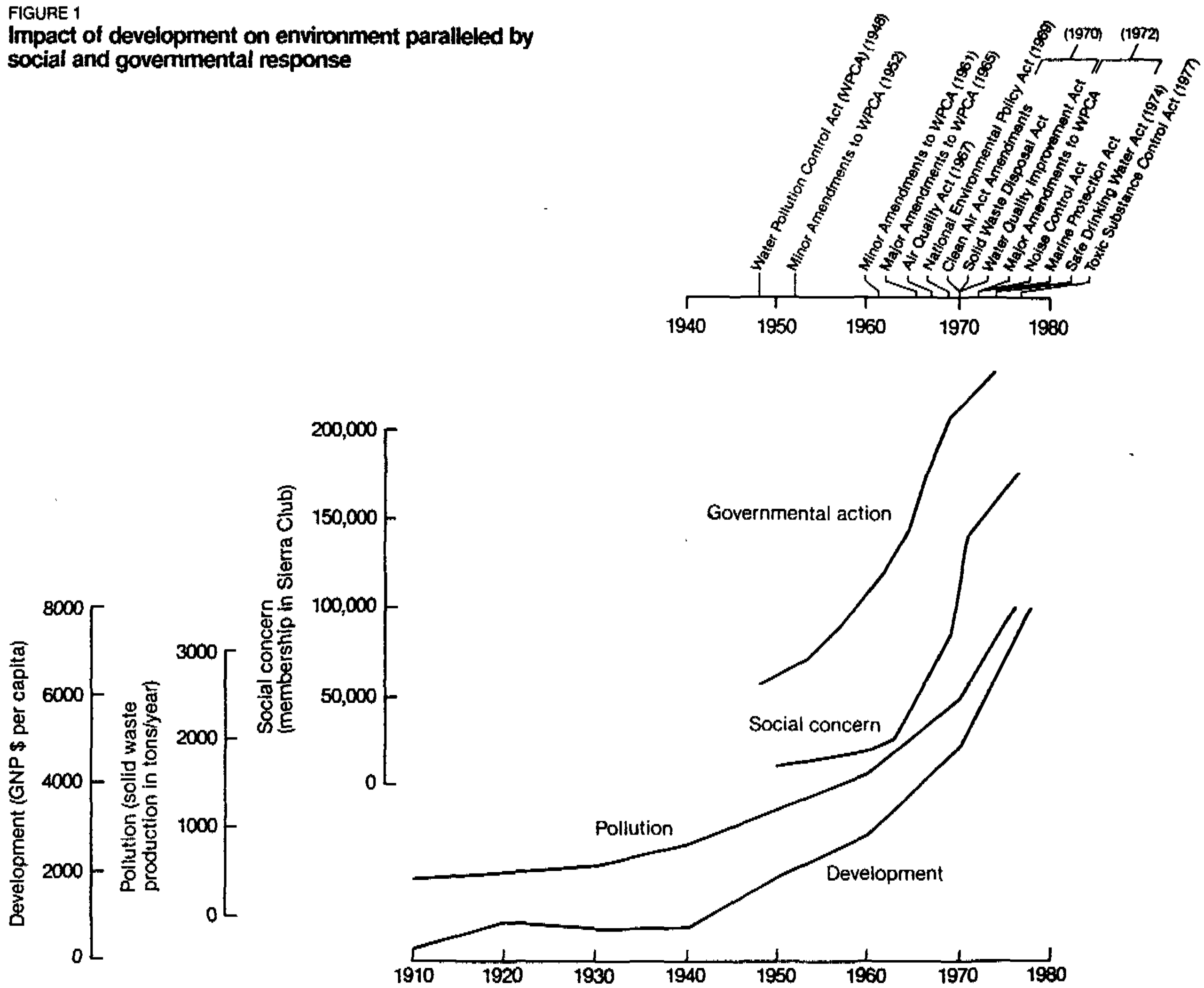
Four different, but related, historical reasons for this lag in discovery of the TCE problem in the Sacramento area are identified and discussed below.

- The environmental consciousness of U.S. citizens was not awakened until the mid-1960s.
- A general knowledge of the fate of TCE in the environment and its potential deleterious effects on human health was absent until the late 1970s.
- The capability to reliably measure

TCE: The ideal degreasing solvent and why

- TCE has high solvency for oils, greases, waxes, tars, resins, lubricants, and coolants generally found in the metal-processing industry.
- TCE will not attack steel, copper, zinc, or other metals used in industry.
- TCE was considered to have low toxicity; until the mid-1970s, the air standard for environmental exposure ranged from 100 to 200 ppm.
- TCE is nonflammable and nonexplosive at ordinary temperatures.
- TCE has a high vapor density (*4.5 times that of air*); this results in maintenance of a distinct vapor level near condensing coils in degreasing tanks and prevents excessive vapor losses to the surrounding atmosphere.
- TCE is highly stable in the presence of common chemical stabilizers.
- TCE has a low boiling point (87.1 °C); this permits low heat input and facilitates handling of work following degreasing operations.

FIGURE 1
Impact of development on environment paralleled by social and governmental response



Source: Reference 15.

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trace concentrations of TCE in aqueous samples was not developed until the mid-1970s.

- Specific laws and regulations for TCE were not promulgated until the late 1970s to early 1980s.

Environmental consciousness

Immediately following World War II and through the mid-1960s, the prevailing interest in the United States was economic recovery and prosperity. Little attention was paid to the rapidly degrading and abused environment. The graph in Figure 1 *(15)* shows how environmental contamination paralleled resource development in the United States during the 1950s and 1960s. Few people at the time were aware that economic growth, based on the exploitation of natural resources, would produce enormous quantities of residues that had to come to rest somewhere in the environment. And this phenomenon, which could have been predicted from the basic laws of thermodynamics, resulted in serious water, air, and land pollution nationwide *(16)*.

By the mid-1960s, in the absence of effective regulations and enforcement, environmental degradation had become severe and was no longer tolerated by the citizenry as an acceptable trade-off for economic gain. This change in attitude toward environmental quality marked the beginning of the environmental movement in the United States. This change is quantified in Figure 1 by the growth in membership in the Sierra Club, a national environmental organization. This change is also demonstrated in Figure 2 by the increase in environment-related articles in the press during the late 1960s.

As public concern about the environment intensified, the Congress became responsive to public demands and enacted an increasing number of rigorous environmental laws. Some of the major legislation is shown in Figure 1.

TCE viewed as a hazard

During the past 50 years, several trends in environmental focus or interest can be identified, as shown in Figure 3. The chart plots the number of articles that were indexed in the *Journal of the Water Pollution Control Federation* about selected categories of chemical contaminants. (Each year the *JWPCF* publishes an index of the world literature that relates in some way to the field of water quality.) The articles are contributions from university researchers, governmental regulators, waste treatment facility operators, equipment representatives, and, on occasion, concerned citizens. The numbers of articles about detergents, pesticides, and heavy metals plotted in Figure 3 are close approximations because duplications of listings were not determined and because the selection of articles was based solely on the abstracted descriptions in the literature review.

It is my contention that an increase in the number of publications about a subject area represents an increase in societal awareness or concern about that subject. The number of articles published and the areas of emphasis also reflect the availability of research funding from government and other sources. It is interesting to note that each of the four trends identified in Figure 3 was initiated by societal concern and action rather than by farsighted leadership by universities. Universities have generally only responded to problems and have focused research primarily where funding is available.

Figure 3 shows that the middle to late 1960s might be termed the "era of detergents" in environmental history. Detergents provoked public ire when foam and scum were visible on rivers, lakes, and harbors. The problem was essentially solved by the replacement of nonbiodegradable detergents with biodegradable formulations that had

FIGURE 2
Environment-related articles in *The New York Times*

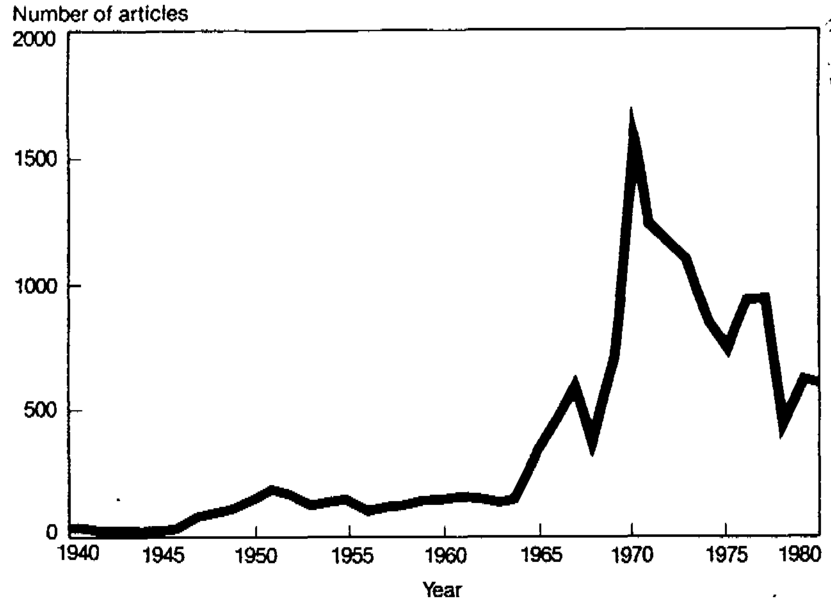
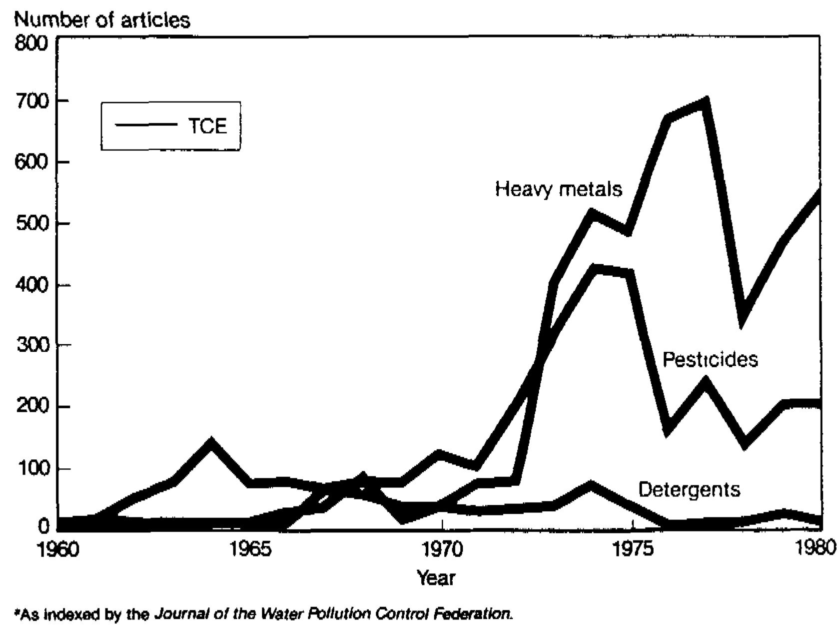


FIGURE 3
Number of articles in the world literature on chemical contaminants*



*As indexed by the *Journal of the Water Pollution Control Federation.*

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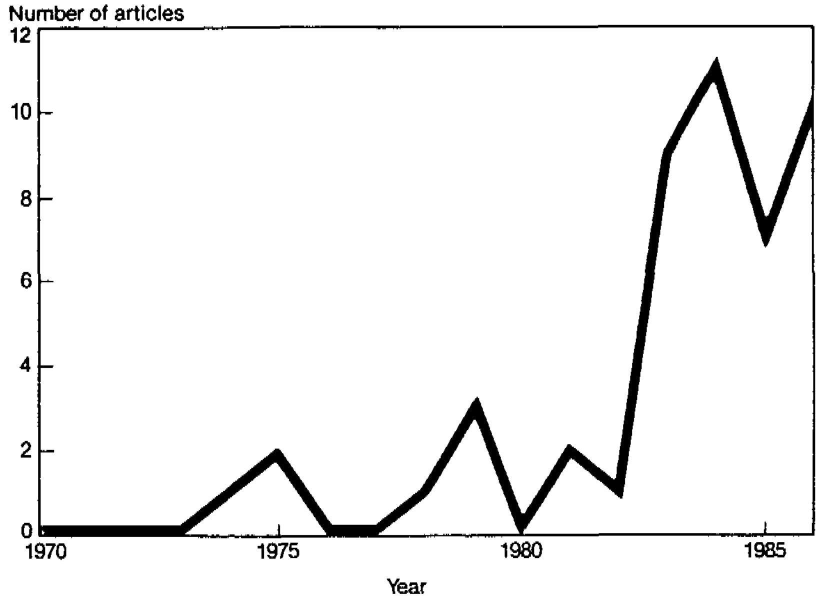
FIGURE 4
Articles on TCE in the world literature[a]



[a]As indexed by the *Journal of the Water Pollution Control Federation.*

comparable cleaning properties. Societal interest then declined significantly, as did the number of publications on the subject.

The "era of pesticides" began in the late 1960s and was prompted, in large measure, by the popular book *Silent Spring* by Rachel Carson *(17)*. The era of pesticides has continued to the present because these chemicals remain in common use and are considered to be toxic, hazardous substances.

The "era of heavy metals" is shown in Figure 3 to have begun in the early 1970s. In 1969 fewer than 50 articles about heavy metals appeared in the literature. By contrast, nearly 700 articles were published on this subject in 1977. Early concerns about chromium from tanning and dyeing intensified as the metal plating industry developed. Plating wastes included chromium, zinc, cyanide, and other highly toxic chemicals. Later concerns focused on lead in gasoline and paint products, cadmium, mercury (causing Mikimoto disease), and other heavy metals. Heavy metals continue to be used extensively by industry and in homes, and serious problems of environmental contamination are prevalent throughout the country.

The final era identified in the chart in Figure 3, and shown in expanded scale in Figure 4, might be referred to as the "era of chlorinated solvents," which began in the late 1970s in response to the infamous Love Canal situation. Prior to the 1980s, the paucity of technical literature about this category of chemicals suggests that there was little concern about chlorinated solvents in university research programs, regulatory agencies, industry, or the general public. Recently however, considerably more interest in these chemicals has been generated, as many have now been identified as hazardous substances that have been, and continue to be, used in industry (as solvents), in commerce (in dry cleaning), and in homes (in cleaners, cosmetics, and other common household products) *(13)*.

Availability of analytical methods

The analytical capability for detecting and measuring environmental contaminants has expanded greatly in recent years in both precision and sophistication. This has resulted in the discovery of environmental contamination which has heretofore existed but which could not have been detected by less sensitive analytical techniques and devices. Such is the case with TCE.

Prior to the mid-1970s, there were no analytical methods available to environmental analysts to measure, or even detect, specific chlorinated solvents such as TCE in water. The Fujiwara colorimetric method of TCE determination was commonly used, but had many shortcomings—most notably its inability to distinguish TCE from other chlorinated solvents *(18)*. Other limitations included the need to keep all reagents absolutely dry, the need for precise volumetric measurement, and the rapid decay of color density—the basis for measurement. Then in 1974, Bellar and Lichtenberg *(19)* described a gas chromatographic method that could separate and detect chlorinated solvents in water in the parts-per-billion range. As a consequence of this and other developments in analytical capability, environmental regulators were able to test water samples for TCE. They found the substance in groundwater aquifers nationwide.

The evolution of techniques for the measurement of chlorinated substances in aqueous samples is illustrated in the semiquantitative plot in Figure 5. The plot reflects the methodology generally available to the environmental profession as evidenced in the bible of water analysis, *Standard Methods for the Examination of Water and Wastewater.* (*Standard Methods* is published jointly by the American Public Health Association, the American Water Works Association, and the Water Pollution Control Federation and is edited and updated approximately every five years. New methods of analysis that are proposed for inclusion in the publication must first be thoroughly evaluated by qualified environmental chemists in selected laboratories.)

Figure 5 shows that *Standard Methods* did not include any methods for the analysis of chlorinated pesticides or chlorinated solvents prior to the 12th edition in 1965 *(20)*. This edition made a brief reference to gas-liquid chromatography as a "potential" method of pesticide analysis. It was not until the 13th edition in 1971 *(21)*, however, that even a "tentative" method was adopted; and this method was only for pesticides. A method for chlorinated solvents did not appear in *Standard Methods* until the 15th edition published in 1980 *(22)*.

There is little doubt that the significant improvements in analytical sophistication and detection sensitivity have profoundly affected our ability to evaluate and manage environmental quality. It is highly likely, however, that our ability to detect and measure contaminants far exceeds our ability to properly and responsibly evaluate the impacts of those concentrations on human health, on other biological life, and on overall environmental quality.

Industrial standards of practice

Environmental management in the United States has long featured problem identification by society; legal mandate by Congress; detailed regulation by appropriate governmental pollution control agencies; response to regulation by industry, municipalities, and other dischargers of waste; and conflict resolution in the courts. This management approach, by default or by design, has placed the responsibility for environmental problem evaluation and resolution on government. It is regrettable that our universities and technical,

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professional, and scientific societies have not assumed a stronger leadership role in environmental protection.

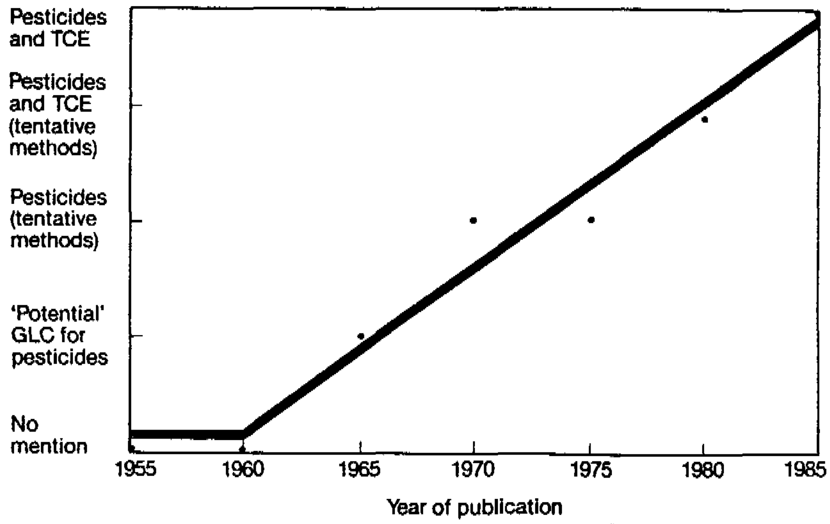
Over the years, industries that produced wastes generally sought to dispose of them by the most readily available and economical methods consistent with environmental regulations in effect at that time. That practice continues to this day. The methods of treatment and disposal that were commonly used throughout an industry or segment of an industry are referred to as "industry standards of practice." History has shown that as environmental laws and regulations became more rigorous, and as new and better methods for treatment and disposal were developed, the standard of practice for industry (and municipalities) increased in sophistication and rigor.

In retrospect, it is very tempting to criticize industries for standards of practice for handling hazardous substances that were adopted in the 1940s, 1950s, 1960s, and even into the 1970s, because as a result of those practices we now find contaminated groundwater throughout the country. But to judge fairly, one must determine whether the methods used for waste management in the past were "reasonable" for the level of knowledge at that time.

A good example is the handling and disposal of TCE. It continued to be used for several reasons in addition to its solvent properties.

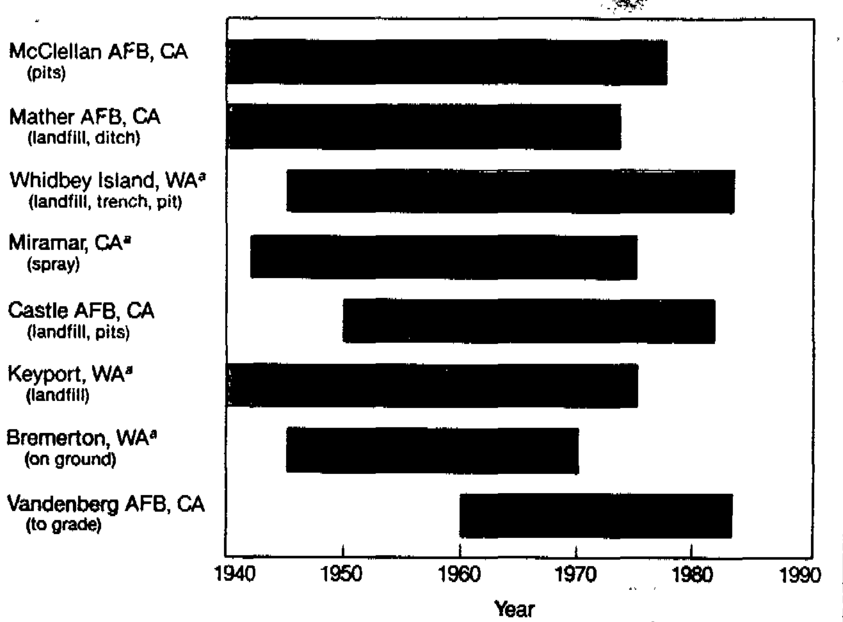
- TCE was considered to be safe for human contact because it was being used by the health profession through the 1970s as an anesthetic. It was also approved for extensive use in food production by the Food and Drug Administration through the late 1970s.
- There were no federal, state, or local laws or regulations that restricted or banned TCE in liquid effluents until the late 1970s.
- There were no analytical methods available to test for this substance in low concentrations until the mid to late 1970s, so detection in groundwater would have been impossible had it been suspected.
- It was not until the mid-1970s that TCE was determined to be a "suspected carcinogen."
- TCE was disposed of directly onto the land at military installations through the 1970s (Figure 6), yet the military had the same responsibilities for environmental protection as industry or municipalities.
- The nation's universities did not provide educational opportunities in hazardous-waste management until the 1980s, so few people in government and industry were trained to identify and effectively react to hazardous-waste problems. Figure 7 shows the increase in availability of hazardous-waste courses at U.S. universities.

FIGURE 5
Development of analysis methods for chlorinated pesticides and TCE[a]



[a]As published in References 20, 21, and 22.

FIGURE 6
Land disposal of TCE at military installations



[a]Naval bases

Summary

The case against the use of TCE in the work place and its disposal in small quantities in the environment is shaky at best. However, the current environmental regulatory posture of our society apparently is: "If we err, err on the side of conservatism." But this conservatism is not without huge societal costs.

Toxic tort litigations involving TCE are running in the billions of dollars; remedial actions involving groundwater and soil cleanup to essentially nondetectable levels are costing billions of dollars; and, perhaps most importantly, the populace has been unduly traumatized by overreactive publicity and allegations regarding the deleterious health effects of TCE. It is interesting to note that some "accepted" alternatives to TCE for degreasing since the mid-1970s have been trichloroethane (TCA) and freon. TCA is now on the EPA list of suspected carcinogens, and freon is implicated in the destruction of the ozone layer.

Although Figure 4 shows an increas-

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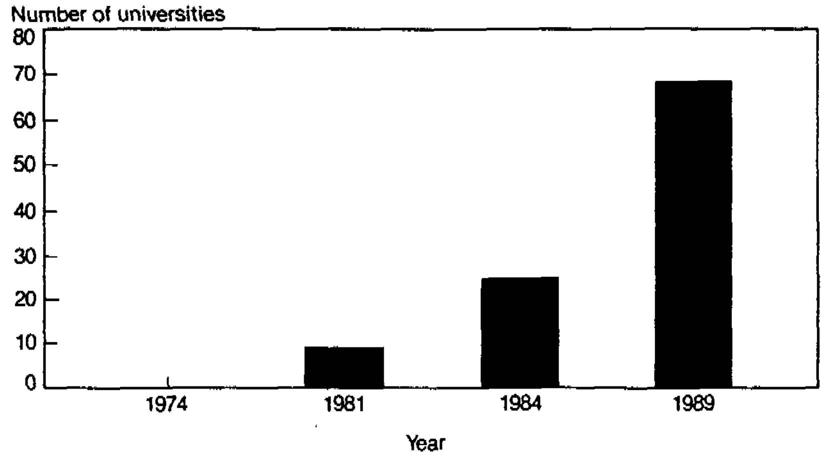
FIGURE 7
Increase in hazardous-waste courses at U.S. universities



Source: *AEEP Register,* Vol. III–VI.

ing number of publications relating to chlorinated solvents during the 1980s, the absolute numbers remain quite small in comparison to those that reflect other chemicals of environmental concern (Figure 3). This suggests that the level of interest in and concern about chlorinated solvents remains relatively low; and low government priority has meant a low funding level for basic and applied research.

Another factor affecting a rise in interest in chlorinated solvents is the lack of compelling evidence of significant harm to human health or environmental quality. Only in the courts has this substance taken on dimensions of enormous significance.

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