1,1-Dichloroethylene (Vinylidene Chloride)

Occurrence in
Drinking Water,
Food, and Air

Science and Technology Branch
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JRB Associates

OCCURRENCE OF 1,1-DICHLOROETHYLENE IN DRINKING WATER, FOOD AND AIR

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SUMMARY

This report presents information on the occurrence of 1,1-dichloroethylene in public drinking water supplies and ambient air in the United States and an estimate of human intake of 1,1-dichloroethylene from those sources. There were no data available on the occurrence of 1,1-dichloroethylene in food. Federal survey data on 1,1-dichloroethylene levels in drinking water systems were combined and stratified according to water source (surface and ground) and size based on population served. These data were used to develop a national profile of 1,1-dichloroethylene levels in drinking water that provides estimates of the number of systems of each source/size category, and the total population served by them, at each exposure level. The relative contribution of drinking water to total human intake of 1,1-dichloroethylene is estimated by analyzing data on levels of this chemical in ambient air and estimating the likely range of 1,1-dichloroethylene combined intake from drinking water and air for a 70 kg man and a 3.5 kg formula-fed infant.

1,1-Dichloroethylene ($CH_2=CCl_2$), also known as vinylidene chloride, is a colorless liquid. It has a high vapor pressure (495 mm Hg at 20°C) and a low water solubility (0.035 g/100 g at 25°C).

Production of 1,1-dichloroethylene in 1978 was estimated to be 144,200 kkg. This figure included 1,1-dichloroethylene captively produced for the production of methyl chloroform. However, 1,1-dichloroethylene appears no longer to be used in methyl chloroform production. In addition to its direct manufacture, 1,1-dichloroethylene may be produced indirectly during the production of other chlorinated chemicals.

The major uses of 1,1-dichloroethylene in 1978 were the production of methyl chloroform and the production of copolymers for use in resins, coating latex, and the manufacture of modacrylics. A minor application was its use in the production of chloroacetyl chloride, a component of mace and tear gas.

Total releases of 1,1-dichloroethylene from production and use processes in 1978 were estimated to be 2,000 kkg to air, 0 kkg to land, and 2 kkg to water. However, the production and use of methyl chloroform was estimated to account for 1,300 of the 2,000 kkg of 1,1-dichloroethylene released to air in 1978, and methyl chloroform no longer appears to be produced by this pro-

cess. The production of copolymers is currently estimated to account for almost all environmental releases of 1,1-dichloroethylene. Quantities of 1,1-dichloroethylene entering water are expected to be volatilized and to undergo rapid degradation in the troposphere.

Two Federal surveys were used to estimate levels of 1,1-dichloroethylene in the nation's public drinking water supplies: the National Screening Program for Organics in Drinking Water (NSP) and the Groundwater Supply Survey (GWSS). Additional state data are also reported, but were not used in developing the national estimates. These data came from only a few states and were not well-characterized with respect to water type and system size sampled.

There are approximately 60,000 public water supplies in the United States serving approximately 214 million people. These supplies fall into two categories with respect to water source (surface water and groundwater) and into five major size categories (with twelve size subcategories) according to the number of individuals served. The data obtained from the two Federal studies was combined and sorted by source and size category in order to develop estimates of the number of systems nationally in each source/size category containing 1,1-dichloroethylene within various concentration ranges. The national estimate of systems was used to calculate the number of persons exposed to public drinking water containing 1,1-dichloroethylene levels in those ranges.

Using the combined survey data and the multinomial approach for estimating national occurrence, it was calculated that about 98% of the groundwater systems of all sizes contain either no 1,1-dichloroethylene or levels less than 0.2 ug/l. It is not possible, however, to estimate how many of these systems contain 1,1-dichloroethylene at low levels and how many are free of 1,1-dichloroethylene contamination. Of the estimated 858 systems expected to have levels higher than 0.2 ug/l, 81 (0.2% of total groundwater systems) are projected to have concentrations > 5 ug/l; none are expected to have levels > 10 ug/l. The state data, however, indicate that there may be some supplies with levels substantially higher than 10 ug/l.

For surface water supplies, it is estimated that about 99.7% will have either no 1,1-dichloroethylene present or levels < 0.2 ug/l. It is estimated that 35 surface water systems have levels ≥ 0.2 ug/l (0.3% of total surface water systems); none are estimated to have 1,1-dichloroethylene above 5 ug/l.

It is important to note that some of the data used in computing the national estimates are from samples held for a prolonged period of time prior to analysis, with possible biodegradation of 1,1-dichloroethylene. Therefore, these projections of national occurrence may underestimate actual contaminant levels.

Using combined data from surface water and groundwater supplies, it was estimated that 209,630,000 persons (97.8% of the population served by public drinking water systems) are receiving water with no 1,1-dichloroethylene or levels less than 0.2 ug/l. Of the 4,789,000 persons (2.2%) receiving water containing 1,1-dichloroethylene levels $\geq$ 0.2 ug/l, an estimated 52,000 (< 0.1%) are exposed to levels > 5 ug/l. No individuals are estimated to be exposed to levels > 10 ug/l. Of the approximately 4.7 million people estimated to be exposed to levels ranging from 0.2 to 5 ug/l, 52% obtain water from surface water supplies. All exposure to 1,1-dichloroethylene in drinking water at levels above 5 ug/l is expected to be from groundwater sources. It was also estimated that 40,000 formula-fed infants are exposed to 1,1-dichloroethylene levels greater than 0.2 ug/l and 440 formula-fed infants are exposed to levels in excess of 5 ug/l. An adjustment of drinking water levels for formula-fed infants was made to account for 1,1-dichloroethylene removal from drinking water that is boiled prior to adding it to the formula.

The daily intake of 1,1-dichloroethylene from drinking water has also been estimated. The majority of persons using public drinking water supplies would be exposed to intake levels at or below 0.0057 ug/kg/day for adults and 0.048 ug/kg/day for formula-fed infants. Those individuals exposed to drinking water containing higher levels of 1,1-dichloroethylene (> 5 ug/l) would receive an intake of 1,1-dichloroethylene greater than 0.14 ug/kg/day for adults and 1.2 ug/kg/day for infants.

No data were obtained on levels of 1,1-dichloroethylene in foods. Therefore, the daily intake of 1,1-dichloroethylene could not be estimated.

Data on levels of 1,1-dichloroethylene in ambient air in the United States were used to determine the respiratory intake of 1,1-dichloroethylene. It was estimated that rural/remote, urban/suburban, source dominated, and maximum levels of 1,1-dichloroethylene in ambient air would approximate 0.0, 0.020, 14, and 27 ug/m^3, respectively. Using these data, respiratory intake for the adult male was estimated to vary between 0 and 8.9 ug/kg/day. Respiratory intake for formula-fed infants would vary between 0 and 6.2 ug/kg/day.

The total daily multimedia intake of 1,1-dichloroethylene was estimated using a range of low to high intake values for air and drinking water exposure. Total intake was estimated to range from 0-9.2 ug/kg/day for the adult male and from 0-86 ug/kg/day for the formula-fed infant. At an air level of 0.020 ug/m^3, drinking water will be the predominant source of 1,1-dichloroethylene exposure in the adult male at drinking water levels of 0.2 ug/l and above. In contrast, for the formula-fed infant exposed to the same ambient air level (0.020 ug/m^3), drinking water will be the predominant source of 1,1-dichloroethylene exposure at levels above 0.02 ug/l.

Population-exposure estimates for 1,1-dichloroethylene in drinking water were calculated to range from 0.024-1.3 x 10^8 ug/day x persons.

INTRODUCTION

Monitoring studies of drinking water supplies in recent years have uncovered evidence of contamination by volatile organic chemicals (VOC's). On March 4, 1982, the Environmental Protection Agency (EPA) published an Advance Notice of Proposed Rulemaking that discussed regulatory and nonregulatory approaches for limiting human exposure to 14 specific VOC's identified to be of particular concern as drinking water contaminants (47 FR 9350). 1,1-Dichloroethylene, the subject of this report, is one of those 14 chemicals.

This report presents information on the occurrence of 1,1-dichloroethylene in drinking water, food, and air. This information is intended to provide support for EPA's assessment of 1,1-dichloroethylene in two principal areas. As input to the health risk assessment, this report provides an estimate of the number of individuals in the United States exposed to various levels of 1,1-dichloroethylene in drinking water from public water supplies. Information on dietary intake and respiratory intake from ambient air is provided for perspective and is used to estimate the relative contributions of the three sources, particularly of drinking water, to the total dose received by individuals. While it is recognized that some individuals may be exposed to 1,1-dichloroethylene from other sources, such as occupational settings or the use of particular consumer products, this analysis is limited to drinking water, food, and air because these are the major exposure routes common to all individuals.

In addition to serving as input to the health assessment, this report supports EPA efforts to estimate the economic impact of the regulatory and treatment alternatives being considered. To aid in that effort, estimates are provided of the number of public water supplies of various water source and system size characteristics having 1,1-dichloroethylene present, and the distribution of 1,1-dichloroethylene levels in those water supplies.

An extensive body of published and unpublished information is available on 1,1-dichloroethylene relevant to its occurrence in the environment. This report is based on information published since about 1965 and, where appropriate, utilizes EPA- and government-sponsored studies on the occurrence of and human exposure to 1,1-dichloroethylene. This report is not intended to be an exhaustive, comprehensive review of all existing data on 1,1-dichloro-

ethylene. It does, however, present the most current and representative information available for understanding the occurrence of 1,1-dichloroethylene in food, air, and drinking water, and for assessing the importance of drinking water as a route of human exposure.

A previous version of this report was prepared on September 2, 1982 and was distributed at EPA for review. In this version, the authors have attempted to reflect the many valuable comments and suggestions made by the reviewers.

1. SOURCES OF 1,1-DICHLOROETHYLENE

1,1-Dichloroethylene, also known as vinylidene chloride (VDC), is a colorless liquid with a low boiling point (31.6°C), very high vapor pressure (495 mm Hg at 20°C), and low solubility in water (0.035 g/100 g at 25°C) (Farmer et al. 1980). 1,1-Dichloroethylene is used in the manufacture of copolymers that are incorporated in a variety of fibers and packing films. It is also used to a lesser extent in the manufacture of chloroacetyl chloride, a component of mace and tear gas.

1.1 NATURAL SOURCES

The limited monitoring data on 1,1-dichloroethylene do not indicate any natural production of the chemical. No natural processes that generate 1,1-dichloroethylene have been identified.

1.2 ANTHROPOGENIC SOURCES

1.2.1 Production

Two manufacturers with a total of three plants (i.e., Dow Chemical in Freeport, Texas and Plaquemine, Louisiana, and PPG Industries in Lake Charles, Louisiana) produced most of the domestic 1,1-dichloroethylene in 1978. Production data for 1,1-dichloroethylene are not readily available; the most recent figure is 144,200 kkg for 1978 (Farmer et al. 1980). This figure includes the 1,1-dichloroethylene that was captively consumed in the production of methyl chloroform. However, 1,1-dichloroethylene appears no longer to be used in methyl chloroform production.

The most common process for production of 1,1-dichloroethylene involves the dehydrochlorination of 1,1,2-trichloroethane by dilute sodium hydroxide. 1,1-Dichloroethylene can also be produced by the chlorination of ethane or ethylene when market conditions make this process more favorable (Farmer et al. 1980).

1,1-Dichloroethylene can also be produced indirectly as a byproduct during several industrial processes (Farmer et al. 1980):

1) Manufacture of 1,2-dichloroethane by the oxychlorination of ethylene;

2) Production of vinyl chloride monomer from 1,2-dichloroethane;

3) Oxychlorination and chlorination processes for the production of tetrachloroethylene and trichloroethylene; and

4) Production of chloroprene.

Estimates for direct and indirect production of 1,1-dichloroethylene and environmental release data are presented in Table 1.

Table 1. 1978 Production and Associated Releases of 1,1-Dichloroethylene

Process	Amount (kkg)	Releases to environment (kkg)		
		Air	Land	Water
Direct Production				
Production from 1,1,2-trichloroethane	144,200	10	--	--
Indirect Production				
Production of 1,2-dichloroethane	100	100	--	--
Production of vinyl chloride from 1,2-dichloroethane	Unknown	--	--	--
Contaminant of vinyl chloride	20	< 2	--	--
Production of tetra- and trichloroethylene via oxychlorination of 1,2-dichloroethane	112	8	--	--
Production of tetrachloroethylene via chlorination of 1,2-dichloroethane	146	91	--	--

Source: Farmer et al. 1980

1.2.2 Consumption

In 1978, an estimated 63,200 kkg of 1,1-dichloroethylene were captively consumed in the production of methyl chloroform, with an additional 9 kkg present in the end product as an impurity (Farmer et al. 1980). This use accounted for nearly 45% of the total 1,1-dichloroethylene produced. Of the

remaining 81,000 kkg, an estimated 78,200 kkg were used in the production of polyvinylidene chloride (PVDC) for use in resins, coating latex, and in the manufacture of modacrylics. Other uses included exports and the production of chloroacetyl chloride. Quantitative estimates of the end uses, based on 1978 production figures, are found in Table 2.

Table 2. End Uses of 1,1-Dichloroethylene and Associated Environmental Releases in 1978

Uses	Quantity (kkg)	Releases to environment (kkg)		
		Air	Land	Water
Methyl chloroform production	63,200	1,264	--	--
Use of methyl chloroform	9 (as impurity)	9	Neg	Neg
Production of PVDC speciality latexes for rug backing	4,690	66	--	Neg
Production of modacrylics	10,005	Neg	--	--
Production of PVDC emulsion/suspension latex	63,470	254	--	2
Other PVDC uses	< 5	< 5	Neg	Neg
Production of chloroacetyl chloride	2,835	0	0	0
Exports	Neg	--	--	--

Source: Farmer et al. 1980

1.2.3 Releases

The principal estimated environmental releases associated with production and use of 1,1-dichloroethylene in 1978 are shown in Tables 1 and 2. Major releases are to the atmosphere. The manufacture of 1,1-dichloroethylene results in a relatively small release to the atmosphere. Of 995 kkg estimated to be released from reactor and distillation vents in this process in 1978, only 1% (10 kkg) was emitted to the atmosphere; the remainder was incinerated as gaseous waste (Farmer et al. 1980).

Although 1,1-dichloroethylene is no longer used in the production of methyl chloroform, in 1978 this process accounted for nearly 70% of the estimated air releases of 1,1-dichloroethylene. Any 1,1-dichloroethylene retained in methyl chloroform as an impurity would be released to the environment when the product was used as a vapor degreaser, and in adhesives, aerosols, paints, inks, textiles, and drain cleaners. As a result, negligible amounts of 1,1-dichloroethylene were estimated to be released to water (drain cleaners) and land (landfill of aerosol cans) from the manufacture and use of methyl chloroform (Farmer et al. 1980).

Most current releases of 1,1-dichloroethylene are expected to result from other uses, among them production of PVDC and its use in the manufacture of other products. The largest estimated amount of 1,1-dichloroethylene released in this manner in 1978 came from the production of PVDC emulsion/suspension latex (254 kkg to air, with 2 kkg to water). Lesser amounts were also released during the manufacture of specialty latexes, and the use of PVDC resin in Saran, coating latexes, and solvent coatings. No releases of 1,1-dichloroethylene were reported from the production of chloroacetyl chloride, nor is it present as an impurity. Releases from exports were negligible (Farmer et al. 1980).

1.3 FATE AND TRANSPORT

Large amounts of 1,1-dichloroethylene enter the troposphere through air emissions. In addition, volatilization appears to be the major transport process for removal from the aquatic environment (Callahan et al. 1979). In the troposphere, 1,1-dichloroethylene is photooxidized, resulting in production of chloroacetyl chloride, phosgene, formic acid, hydrochloric acid, carbon monoxide, and formaldehyde. The tropospheric lifetime is estimated to be less than 1 day (Callahan et al. 1979).

Bioaccumulation of 1,1-dichloroethylene in the aquatic environment is not thought to be significant (Callahan et al. 1979). No data on biotransformation and biodegradation are available.

2. OCCURRENCE IN DRINKING WATER

1,1-Dichloroethylene is a synthetic organic chemical whose major routes of entry to drinking water are a consequence of industrial activity. Quantities of 1,1-dichloroethylene in water may result from industrial discharge, atmospheric fallout, or the release of quantities remaining as impurities in products.

It is currently estimated that there are 59,660 public water supplies in the United States (FRDS 1983). As shown in Table 3, 48,458 of the supplies use groundwater and 11,202 use surface water as their primary source. Table 3 also shows the distribution of groundwater and surface water supplies among the five major size categories and twelve subcategories based on the population served.

There are two major types of data available that are potentially useful for describing the occurrence of 1,1-dichloroethylene in the nation's public drinking water supplies. First, there are several Federal surveys in which a number of public water supplies from throughout the U.S. were selected for analysis of chemical contamination, including 1,1-dichloroethylene. Second, data are available from state surveys and from state investigations of specific incidents of known or suspected contamination of a supply. For accomplishing the basic objectives of this study, namely to estimate the number of public water supplies nationally within the various source and size categories contaminated with 1,1-dichloroethylene, the distribution of 1,1-dichloroethylene concentrations in those supplies, and the number of individuals exposed to those concentrations, it was determined that the Federal survey data provides the most suitable data base. The state data tend to be poorly described with respect to the source and size categories of the supplies examined and the sampling and analysis methods used for determining contaminant levels. The lack of source and system size information precludes using the data for estimating levels in public water supplies of similar characteristics. The absence of details on sampling and analysis methods precludes evaluating those data for their qualitative and quantitative reliability. Also, because much of the state data are from investigations in response to incidents of known or suspected contamination (e.g., spills), they were judged to be not representative of contaminant levels in the nation's water supplies in general. Although they are not used with the Federal data for the purpose

of estimating contamination levels nationally, the available state data are presented here to provide some additional perspective on 1,1-dichloroethylene occurrence in drinking water.

This section of the report, which contains information on the occurrence of 1,1-dichloroethylene in drinking water supplies in the United States, is divided into four major parts. Section 2.1 presents an overview of the Federal surveys providing data on 1,1-dichloroethylene. The methods of analysis used in each survey are discussed and an evaluation of the qualitative and quantitative acceptability of the data is reported.

Sections 2.2 and 2.3 present the data available from the Federal and state sources on the occurrence of 1,1-dichloroethylene in groundwater and surface water supplies, respectively. Data are presented only on drinking water samples taken from a consumer's tap (i.e., distribution water samples) or on treated water samples taken at the water supply (i.e., finished water samples) because these are considered to be most representative of the water consumed by the public. No data on raw (i.e., untreated) water are presented. It is recognized that for some groundwater supplies where no treatment of the water occurs, samples identified as raw may be representative of water consumed by the users of the supply. However, it was generally not possible to differentiate between those groundwater supplies that do and those that do not treat raw water from the available survey data.

Section 2.4 presents projections, based on the data from the Federal surveys, of the occurrence of 1,1-dichloroethylene in the approximately 60,000 public water supplies in the nation.

Table 3. Number of Systems and Population Served by Primary Water Supply Source (By Population Category)

System size (Population served)		Surface			Groundwater		
		No. of systems	Population (thousands)	Average population served	No. of systems	Population (thousands)	Average population served
Very small	25-100	1,525	86	56	19,125	1,031	54
	101-500	2,412	690	286	15,674	3,814	243
Small	501-1,000	1,377	1,051	763	4,877	3,590	736
	1,001-2,500	1,945	3,295	1,700	4,400	7,047	1,600
	2,501-3,300	495	1,445	2,900	891	2,583	2,900
Medium	3,301-5,000	749	3,096	4,100	1,065	4,370	4,100
	5,001-10,000	930	6,763	7,300	1,168	8,404	7,200
Large	10,001-25,000	915[a]	15,595[b]	17,000	835[a]	12,276[b]	15,000
	25,001-50,000	400[a]	13,945[b]	35,000	290[a]	10,977[b]	38,000
	50,001-75,000	155	9,483	61,000	64	3,911	61,000
	75,001-100,000	82	7,131	87,000	14	1,184	85,000
Very large	>100,000	217	78,366	360,000	55	14,286	260,000
TOTALS[c]:		11,202	140,948		48,458	73,475	

[a]Kuzmack 1983, as updated by David Schnare, Office of Drinking Water, U.S. Environmental Protection Agency, in a personal communication with Frank Letkiewicz, JRB Associates, May 25, 1983.

[b]Estimated by JRB Associates (see Appendix A).

[c]Populations do not add to total due to rounding.

Source: FRDS 1983 (except as noted).

2.1 OVERVIEW AND QUALITY ASSURANCE ASSESSMENT OF FEDERAL DRINKING WATER SURVEYS

Two Federal drinking water surveys provide data on 1,1-dichloroethylene: the National Screening Program for Organics in Drinking Water (NSP) and the Groundwater Supply Survey (GWSS). The scope of the surveys, the analytical methods used, and a description of the files accessed to obtain the data from these surveys are presented below. The information available on the analytical methods used in these surveys generally did not include precise definitions of quantification limit, minimum quantifiable concentration, or similar terms used in reporting the results of the analyses. The terms used in this report are those used in the individual surveys, recognizing that they may not always correspond to strict technical definitions.

The **National Screening Program for Organics in Drinking Water (NSP)**, conducted by SRI International from June 1977 to March 1981, examined both raw and finished drinking water samples from 166 water systems in 33 states for 51 organic chemical contaminants. Data are available for 1,1-dichloroethylene on finished water samples from 12 groundwater and 103 surface water supplies.

The NSP data were extracted from Boland (1981) and coded to create an SAS computer file. Analyses were carried out using gas chromatography with an electrolytic conductivity detector. Single values were reported for finished water samples from most supplies in the NSP. For those where multiple sample data were reported, the values were averaged as described in Appendix A. The quantification limit for 1,1-dichloroethylene in the NSP was reported to be 0.1 ug/l. The quantification limit was based on repeated analysis of formulated standards (Boland 1981); however, the confidence intervals used to establish the quantification limits were not reported.

The **Groundwater Supply Survey (GWSS)** was conducted from December 1980 to December 1981 to develop additional data on the occurrence of volatile organic chemicals in the nation's groundwater supplies (Westrick et al. 1983). It was hoped that this study would stimulate state efforts toward the detection and control of groundwater contamination and the identification of potential chemical "hot spots." A total of 945 systems were sampled, of which 466 were chosen at random. The remaining 479 systems were chosen nonrandomly based on information from states encouraged to identify locations believed to have a higher than normal probability of VOC contamination (e.g., locations near landfills or industrial activity).

The GWSS data were made available from EPA's Office of Drinking Water, Technical Support Division in the form of an SAS computer file. The file provided a single analytical result for each supply sampled. One sample of finished water was collected from each supply at a point near the entrance to the distribution system; mercuric chloride was added as a preservative to prevent biodegradation of aromatics. Analyses were made for a total of 34 organic chemicals using purge and trap gas chromatography with an electrolytic conductivity detector for halocarbons. The minimum quantitation limit for 1,1-dichloroethylene was 0.2 ug/l.

Each of the drinking water surveys was evaluated with respect to the validity of the reported occurrence data for a number of organic chemicals, including 1,1-dichloroethylene. The evaluations were carried out by analyzing information about the procedures used for collection and analysis of samples as well as the quality control protocols used. The analyzed compounds dealt with in each study were assigned one of three possible ratings: quantitatively acceptable, qualitatively acceptable (i.e., the substance measured was 1,1-dichloroethylene), and totally unacceptable. In the case of 1,1-dichloroethylene, a qualitatively acceptable rating was given for data from the NSP because of suspected biodegradation of the samples, which were held unrefrigerated for prolonged periods before analysis. 1,1-Dichloroethylene values in excess of the quantitation limit reported for some samples in these studies are qualitatively valid and can be taken as minimum values, representative of samples which probably originally contained 1,1-dichloroethylene at higher concentrations. In the case of the GWSS, all data were rated both quantitatively and qualitatively acceptable.

2.2 GROUNDWATER

2.2.1 Federal Surveys

The National Screening Program for Organics in Drinking Water (NSP) and and the Groundwater Supply Survey (GWSS) both contain data concerning the levels of 1,1-dichloroethylene in groundwater supplies from across the country.

Twelve groundwater supplies were tested for 1,1-dichloroethylene contamination in the NSP. Of these 12 systems, only one was found to be contaminated

with 1,1-dichloroethylene at a level of 0.2 ug/l (Table 4). The quantification limit for 1,1-dichloroethylene was 0.1 ug/l.

In the GWSS, 9 of the 456 randomly chosen water systems serving 25 or more individuals were contaminated with 1,1-dichloroethylene, at concentrations ranging from 0.22-6.3 ug/l. The three systems with the highest values were contaminated at 2.1, 2.2, and 6.3 ug/l. Of the 9 positive systems, 5 were from systems serving populations in excess of 10,000 people (Table 5). The average for all randomly chosen systems was 1.4 ug/l with a standard deviation of 2.0 ug/l; the median was 0.28 ug/l. Of the 473 nonrandom locations sampled serving 25 or more individuals, 15 were contaminated with 1,1-dichloroethylene, at concentrations between 0.22-3 ug/l, the highest values being 0.04, 1.2, and 3 ug/l. Of the 15 positive samples, 10 were from systems serving populations in excess of 10,000 people (Table 6). The average 1,1-dichloroethylene level for the nonrandom systems was 0.59 ug/l with a standard deviation of 0.71 ug/l; the median value was 0.35 ug/l. The minimum quantitation limit for 1,1-dichloroethylene was 0.2 ug/l.

Table 4. Frequency of Groundwater Contamination by 1,1-Dichloroethylene
National Screening Program for Organics in Drinking Water (NSP)

System size (population served)	No. of systems sampled	No. of positive systems[a]	% Positive systems	No. of negative systems[a]	Number of systems with measured concentrations (ug/l) of:		
					< 0.1	0.1-5	> 5
25-100	0	0	0	0	0	0	0
101-500	0	0	0	0	0	0	0
501-1,000	0	0	0	0	0	0	0
1,001-2,500	0	0	0	0	0	0	0
2,501-3,300	1	1	100	0	0	1	0
3,301-5,000	1	0	0	1	0	0	0
5,001-10,000	0	0	0	0	0	0	0
10,001-50,000	0	0	0	0	0	0	0
50,001-75,000	0	0	0	0	0	0	0
75,001-100,000	1	0	0	1	0	0	0
> 100,000	9	0	0	9	0	0	0
Totals	12	1	8	11	0	1	0

[a]Quantification limit = 0.1 ug/l.

Table 5. Frequency of Groundwater Contamination by 1,1-Dichloroethylene
Groundwater Supply Survey (GWSS) -- Random Sites

System size (population served)	No. of systems sampled	No. of positive systems[a]	% Positive systems	No. of negative systems[a]	Number of systems with measured concentrations (ug/l) of: < 0.2	0.2-5	> 5-10	>10
25-100	70[b]	1	1	69	0	1	0	0
101-500	88	1	1	87	0	1	0	0
501-1,000	28	1	4	27	0	0	1	0
1,001-2,500	31	0	0	31	0	0	0	0
2,501-3,300	17	0	0	17	0	0	0	0
3,301-5,000	19	1	5	18	0	1	0	0
5,001-10,000	17	0	0	17	0	0	0	0
10,001-50,000	153	4	3	149	0	4	0	0
50,001-75,000	15	0	0	15	0	0	0	0
75,001-100,000	5	0	0	5	0	0	0	0
> 100,000	13	1	8	12	0	1	0	0
Totals	456	9	2	447	0	8	1	0

[a]Minimum quantitation limit = 0.2 ug/l.

[b]The GWSS also reported 10 systems serving fewer than 25 people with no quantifiable 1,1-dichloroethylene.

Table 6. Frequency of Groundwater Contamination by 1,1-Dichloroethylene
Groundwater Supply Survey (GWSS) -- Nonrandom Sites

System size (population served)	No. of systems sampled	No. of positive systems[a]	% Positive systems	No. of negative systems[a]	Number of systems with measured concentrations (ug/l) of:		
					< 0.2	0.2-5	> 5
25-100	29[b]	0	0	29	0	0	0
101-500	43	0	0	43	0	0	0
501-1,000	34	2	6	32	0	2	0
1,001-2,500	71	0	0	71	0	0	0
2,501-3,300	21	0	0	21	0	0	0
3,301-5,000	42	2	5	40	0	2	0
5,001-10,000	75	1	1	74	0	1	0
10,001-50,000	118	8	7	110	0	8	0
50,001-75,000	17	2	12	15	0	2	0
75,001-100,000	3	0	0	3	0	0	0
> 100,000	20	0	0	20	0	0	0
Totals	473	15	3	458	0	15	0

[a]Minimum quantitation limit = 0.2 ug/l.

[b]The GWSS also reported 6 systems serving fewer than 25 people with no quantifiable 1,1-dichloroethylene.

2.2.2 State Data

Three states (California, Massachusetts, and New Jersey) provided the U.S. Environmental Protection Agency with information concerning 1,1-dichloroethylene contamination in groundwater supplies. Analytical results for samples from three locations in California ranged from undetectable to 50 ug/l. 1,1-Dichloroethylene levels ranged from undetectable to 261 ug/l in 22 samples from six Massachusetts cities. New Jersey provided data from 19 samples from Fair Lawn and Mahwah; 12 of the samples contained undetectable 1,1-dichloroethylene while the other seven samples ranged from 2.7-3.5 ug/l at Mahwah and 0.9-27 ug/l at Fair Lawn (Table 7).

Table 7. State Data on 1,1-Dichloroethylene in Groundwater

Location	Water type	Mean (ug/l)	Range (ug/l)	Total No. of samples	Reference
CALIFORNIA					
Morada	N/S	1.4		1	CA-01
Aerojet General Corp.	N/S		3-50	4	CA-12
Unspecified	N/S	ND		3	CA-01
MASSACHUSETTS					
Acton	F	8.5	2.6-19.5	4	MA-09
Belchertown	F	12.7	2.0-41.5	12 (8 ND)	MA-01
Dartmouth	F	68.4		2 (1 ND)	MA-09
Lunenburg	D	261		1	MA-18
Rowley	F	ND		1	MA-09
Wilmington	F	ND		2	MA-01
NEW JERSEY					
Fair Lawn	N/S, F	13.4	0.9-27	13 (9 ND)	NJ-01
Mahwah	N/S, D	3.1	2.7-3.5	6 (3 ND)	NJ-01

N/S = not specified, F = finished, D = distribution, ND = not detected

2.3 SURFACE WATER

2.3.1 Federal Surveys

Only one federal survey, the National Screening Program (NSP), contains data concerning 1,1-dichloroethylene levels in surface water supplies. During this survey, 106 drinking water systems were analyzed for 1,1-dichloroethylene between June 1977 and March 1981. Of these, two systems contained detectable levels of 1,1-dichloroethylene, with concentrations of 0.2 and 0.51 ug/l (Table 8).

Table 8. Frequency of Surface Water Contamination by 1,1-Dichloroethylene
National Screening Program for Organics in Drinking Water (NSP)

System size (population served)	No. of systems sampled	No. of positive systems[a]	% Positive systems	No. of negative systems[a]	Number of systems with measured concentrations (ug/l) of:		
					< 0.1	0.1-5	> 5
Unspecified	3	0	0	3	0	0	0
25-100	0	0	0	0	0	0	0
101-500	0	0	0	0	0	0	0
501-1,000	0	0	0	0	0	0	0
1,001-2,500	0	0	0	0	0	0	0
2,501-3,300	0	0	0	0	0	0	0
3,301-5,000	1	0	0	1	0	0	0
5,001-10,000	0	0	0	0	0	0	0
10,001-50,000	4	0	0	4	0	0	0
50,001-75,000	4	0	0	4	0	0	0
75,001-100,000	11	0	0	11	0	0	0
> 100,000	83	2	2	81	0	2	0
Totals	106	2	2	101	0	2	0

[a]Quantification limit = 0.1 ug/l.

2.3.2 State Data

Data from two surface water samples were reported from Niagara Falls, New York. Of the two finished water samples, one contained no detectable 1,1-dichloroethylene. The other sample was contaminated with 1,1-dichloroethylene at 0.22 ug/l.

2.4 PROJECTED NATIONAL OCCURRENCE OF 1,1-DICHLOROETHYLENE IN PUBLIC WATER SUPPLIES

There are approximately 60,000 public water supplies in the United States. As shown in Table 3, these systems fall into two major categories with respect to water source (surface water and groundwater) and into five size categories and twelve subcategories according to the number of individuals served. Sections 2.2 and 2.3 presented the available data from Federal surveys and state reports on the occurrence of 1,1-dichloroethylene in drinking water supplies. This section of the report presents estimates of both the number of drinking water supplies nationally within each of the source/size categories expected to have 1,1-dichloroethylene present, and of the concentration of 1,1-dichloroethylene expected to be present in those supplies.

The Appendices to this report describe the methodology used and assumptions made to develop the national estimates. The key features are summarized here. The estimates are based on the data from the Federal surveys only. The state data were not included for several reasons. Generally, these data are from a few states and were not considered to be geographically representative. There was also a general lack of data on the population served by systems measured, the type of water sampled, and the methodologies used to sample, identify, and measure 1,1-dichloroethylene.

The Federal survey data from the NSP and GWSS were pooled together for developing the national projections. It was assumed in combining these surveys that the resulting data base would be representative of the nation's water supplies. In the case of the GWSS data, both the random and nonrandom samples were included in the projections because, as described in Appendix A (A.2.4), a statistical test of the GWSS data showed no statistically significant difference in the frequency of occurrence of positive values or the mean of the positive values of vinyl chloride between the random and nonrandom samples.

Ideally, adequate survey data would be available to develop the national projections separately for each of the twelve system size categories within the groundwater and surface water groups; however, the available data were too limited for this. It was, therefore, necessary to consolidate some of the size categories to have sufficient data for developing the projections. In consolidating data from various size categories, consideration was given to

the potential for there being statistically significant differences in the frequency of occurrence of 1,1-dichloroethylene as a function of system size. The consolidation of size categories therefore involved a balancing of the need to group size categories together to have an adequate data base for developing the national projections against the need to treat size categories separately in order to preserve the influence of system size as a determinant of contamination potential. The consolidation of size categories also took into account EPA's classification of systems into the five major groups as very small (25-500), small (501-3,300), medium (3,301-10,000), large (10,001-100,000), and very large (> 100,000) (Kuzmack 1983).

Once the data were consolidated, statistical models for extrapolating to the national level were tested and an appropriate model selected. In the case of 1,1-dichloroethylene, the multinominal method was used. The frequency of contamination of groundwater and surface water systems at various concentrations was determined for each consolidated size category. For completing the national estimates, it was assumed that the frequency of contamination observed for each consolidated category was directly applicable to each of the system sizes comprising it.

It is important to note that some of the data used in computing the national estimates are from samples held for a prolonged period of time prior to analysis, with possible biodegradation of 1,1-dichloroethylene. Therefore, these projections of national occurrence may underestimate actual contaminant levels.

2.4.1 Projected National Occurrence of 1,1-Dichloroethylene in Groundwater Supplies

The combined 1,1-dichloroethylene groundwater data from the NSP and GWSS surveys are presented in Table 9. It should be noted that the total number of systems sampled indicated in Table 9 is less than the sum of the systems sampled in each individual survey since some supplies were examined in two or more surveys. For those supplies, an average value was computed based on the results of the individual surveys.

As indicated in Table 9, data are available for a total of 938 supplies from the combined surveys. Of these, 25 supplies were reported to have 1,1-dichloroethylene present, at concentrations ranging from 0.2 ug/l to 6.3 ug/l.

Based on the overall distribution of positive values and maximum possible values for those supplies in which 1,1-dichloroethylene was not found, 0.2 ug/l was selected as the common minimum quantifiable concentration for the combined survey data (see Appendix A.2.5). That is, quantitative projections are made of supplies at several concentration ranges $\geq$ 0.2 ug/l, while only a total number for supplies expected to have either no 1,1-dichloroethylene or levels below 0.2 ug/l can be determined.

When the twelve size categories were consolidated into the five major EPA groupings, there was an apparent trend in the frequency of values $\geq$ 0.2 ug/l as a function of size:

Very small	0.9%	(2/230)
Small	2.0%	(4/203)
Medium	2.6%	(4/154)
Large	4.5%	(14/312)
Very large	2.6%	(1/39)
Overall	2.7%	(25/938)

A test for statistical significance revealed that at the $\alpha = 0.05$ level, the difference among the very small, small, and medium categories was not significant; nor was the difference between the large and very large size categories. However, the combined very small, small, and medium categories and the combined large and very large categories were found to be different. Therefore, two consolidated categories were selected for developing the national estimates:

Very small/small/medium (25-10,000)
Large/very large (> 10,000)

As noted previously, the frequency of occurrence of 1,1-dichloroethylene at various concentrations was determined for the two consolidated groups and then applied to the number of supplies nationally within each of the size categories comprising each group.

Table 10 presents the estimates of groundwater supplies occurring nationally within various 1,1-dichloroethylene concentration ranges: Table 11

provides estimates of the cumulative number of groundwater supplies exceeding a given value of 1,1-dichloroethylene and includes bounds based on the 95% confidence intervals for the totals across all size categories. As indicated by Table 11, 858 groundwater supplies (range of 366-1,349), approximately 1.8% of the total groundwater supplies in the United States, are expected to have 1,1-dichloroethylene at levels of $\geq$ 0.2 ug/l; the remaining 47,600 supplies have either no 1,1-dichloroethylene or levels < 0.2 ug/l.

It is estimated that 81 supplies (range of 0-237) are expected to have 1,1-dichloroethylene levels > 5 ug/l; while no supplies are expected to have levels > 10 ug/l. As shown by the data in Tables 10 and 11, most of the supplies with 1,1-dichloroethylene levels $\geq$ 0.2 are expected to be in the smaller size categories. Although, as noted previously, the frequency of 1,1-dichloroethylene occurrence appears to increase with increasing system size, the number of systems affected nationally is greater for the small sizes because there are many more small systems in existence.

Table 9. Reported Occurrence of 1,1-Dichloroethylene in Groundwater Systems -- Combined Federal Data (NPS and GWSS Surveys)

System size (population served)	No. of systems sampled	No. of positive systems[a]	% Positive systems	No. of negative systems[b]	Number of systems with measured concentrations (ug/l) of:			
					< 0.2	0.2-5	> 5-10	>10
25-100	99	1	1	98	0	1	0	0
101-500	131	1	1	130	0	1	0	0
501-1,000	62	3	5	59	0	2	1	0
1,001-2,500	102	0	0	102	0	0	0	0
2,501-3,300	39	1	3	38	0	1	0	0
3,301-5,000	62	3	5	59	0	3	0	0
5,001-10,000	92	1	1	91	0	1	0	0
10,001-25,000	182	8	4	174	0	8	0	0
25,001-50,000	89	4	4	85	0	4	0	0
50,001-75,000	32	2	6	30	0	2	0	0
75,001-100,000	9	0	0	9	0	0	0	0
> 100,000	39	1	3	38	0	1	0	0
Totals	938	25	3	913	0	24	1	0

[a]Positive systems are those with measured levels of 1,1-dichloroethylene.

[b]Negative systems are those in which 1,1-dichloroethylene was not observed. The maximum possible levels, based on minimum quantifiable limits of the analyses done, ranged from 0.1 to 0.2 ug/l.

Table 10. Estimated Number of Groundwater Systems in Each Size Category with 1,1-Dichloroethylene in the Indicated Concentration Ranges (ug/l)

System size (population served)	No. of systems in U.S.	Estimated number of systems with concentrations (ug/l) of:			
		<0.2[a]	0.2-5	>5-10	>10
25-100	19,125	18,799	293	33	0
101-500	15,674	15,407	240	27	0
501-1,000	4,877	4,794	75	8	0
1,001-2,500	4,400	4,325	67	7	0
2,501-3,300	891	876	14	2	0
3,301-5,000	1,065	1,047	16	2	0
5,001-10,000	1,168	1,148	18	2	0
10,001-25,000	835	799	36	0	0
25,001-50,000	290	278	12	0	0
50,001-75,000	64	61	3	0	0
75,001-100,000	14	13	1	0	0
>100,000	55	53	2	0	0
Total	48,458	47,600	777	81	0

[a]Calculated as the difference between the systems expected to have $\geq$ 0.2 ug/l and the total number of systems in that size category. This group includes those having no 1,1-dichloroethylene contamination and those with levels < 0.2 ug/l.

Table 11. Estimated Cumulative Number of Groundwater Systems in Each Size Category with 1,1-Dichloroethylene Exceeding the Indicated Concentration (ug/l)

System size (population served)	No. of systems in U.S.	Estimated cumulative number of systems with concentrations (ug/l) of:		
		≥ 0.2	> 5	> 10
25-100	19,125	326	33	0
101-500	15,674	267	27	0
501-1,000	4,877	83	8	0
1,001-2,500	4,400	75	7	0
2,501-3,300	891	15	2	0
3,301-5,000	1,065	18	2	0
5,001-10,000	1,168	20	2	0
10,001-25,000	835	36	0	0
25,001-50,000	290	12	0	0
50,001-75,000	64	3	0	0
75,001-100,000	14	1	0	0
>100,000	55	2	0	0
Total	48,458	858	81	0
Lower bound[a]		366	0	0
Upper bound[a]		1,349	237	0

[a]From 95% confidence intervals.

2.4.2 Projected National Occurrence of 1,1-Dichloroethylene in Surface Water Systems

Table 12 presents the 1,1-dichloroethylene surface water data from the NSP survey. As indicated in Table 12, data are available for a total of 103 surface water supplies. Of these, 2 supplies were reported to have 1,1-dichloroethylene present at concentrations of 0.2 ug/l and 0.5 ug/l.

Table 12 indicates that all but one of the 103 surface water supplies sampled in the NSP fall in the large and very large size categories (i.e., serving > 10,000 people). Consequently, it was not possible to evaluate the frequency of occurrence of 1,1-dichloroethylene as a function of system size for the very small, small, and medium size categories. In the large size category (serving 10,001-100,000), none of the 19 supplies were found to have 1,1-dichloroethylene present, while 2 of 83 in the very large category (serving > 100,000) had 1,1-dichloroethylene present. The difference in the frequency of occurrence between the large and very large groups was not statistically significant at the $\alpha = 0.05$ level. For the purpose of the national estimates, the groundwater supplies were consolidated into two groups:

Very small/small/medium (25-10,000)
Large/very large (> 10,000)

Again, the frequency of occurrence of 1,1-dichloroethylene at various concentrations was determined for the two consolidated groups and then applied to the number of supplies nationally within each of the size categories comprising each group.

Table 13 presents the national estimates of surface water supplies within various 1,1-dichloroethylene concentration ranges; Table 14 provides estimates of the cumulative number of surface water supplies exceeding a given value of 1,1-dichloroethylene and includes bounds based on the 95% confidence intervals for the totals across all size categories. As indicated by Table 14, 35 surface water supplies (range of 0-81), approximately 0.3% of the total surface water systems in the United States, are expected to have 1,1-dichloroethylene at levels $\geq$ 0.2 ug/l; the remaining 11,167 supplies have either no 1,1-dichloroethylene or levels < 0.2 ug/l. It is estimated that no surface water supplies will have levels > 5 ug/l. Note that all of the supplies with

levels in the 0.2-5 ug/l range are in the large and very large category. The estimate of no occurrence in the smaller categories is based on only one sample and is probably not a reliable estimate.

Table 12. Reported Occurrence of 1,1-Dichloroethylene in Surface Water Systems (NSP)

System size (population served)	No. of systems sampled	No. of positive systems[a]	% Positive systems	No. of negative systems[b]	Number of systems with measured concentrations (ug/l) of:		
					< 0.2	0.2-5	> 5
25-100	0	0	0	0	0	0	0
101-500	0	0	0	0	0	0	0
501-1,000	0	0	0	0	0	0	0
1,001-2,500	0	0	0	0	0	0	0
2,501-3,300	0	0	0	0	0	0	0
3,301-5,000	1	0	0	1	0	0	0
5,001-10,000	0	0	0	0	0	0	0
10,001-25,000	2	0	0	2	0	0	0
25,001-50,000	2	0	0	2	0	0	0
50,001-75,000	4	0	0	4	0	0	0
75,001-100,000	11	0	0	11	0	0	0
> 100,000	83	2	0	81	0	2	0
Totals	103	2	0	101	0	2	0

[a]Positive systems are those with measured levels of 1,1-dichloroethylene.

[b]Negative systems are those in which 1,1-dichloroethylene was not observed. The maximum possible level, based on minimum quantifiable limits of the analyses done, was 0.1 ug/l.

Table 13. Estimated Number of Surface Water Systems in Each Size Category with 1,1-Dichloroethylene in the Indicated Concentration Ranges (ug/l)

System size (population served)	No. of systems in U.S.	Estimated number of systems with concentrations (ug/l) of:		
		<0.2[a]	0.2-5	>5
25-100	1,525	1,525	0	0
101-500	2,412	2,412	0	0
501-1,000	1,377	1,377	0	0
1,001-2,500	1,945	1,945	0	0
2,501-3,300	495	495	0	0
3,301-5,000	749	749	0	0
5,001-10,000	930	930	0	0
10,001-25,000	915	897	18	0
25,001-50,000	400	392	8	0
50,001-75,000	155	152	3	0
75,001-100,000	82	80	2	0
>100,000	217	213	4	0
Total	11,202	11,167	35	0

[a]Calculated as the difference between the systems expected to have $\geq$ 0.2 ug/l and the total number of systems in that size category. This group includes those having no 1,1-dichloroethylene contamination and those with levels < 0.2 ug/l.

Table 14. Estimated Cumulative Number of Surface Water Systems in Each Size Category with 1,1-Dichloroethylene Exceeding the Indicated Concentration (ug/l)

System size (population served)	No. of systems in U.S.	Estimated cumulative number of systems with concentrations (ug/l) of:	
		≥ 0.2	> 5
25-100	1,525	0	0
101-500	2,412	0	0
501-1,000	1,377	0	0
1,001-2,500	1,945	0	0
2,501-3,300	495	0	0
3,301-5,000	749	0	0
5,001-10,000	930	0	0
10,001-25,000	915	18	0
25,001-50,000	400	8	0
50,001-75,000	155	3	0
75,001-100,000	82	2	0
>100,000	217	4	0
Total	11,202	35	0
Lower bound[a]		0	0
Upper bound[a]		81	0

[a]From 95% confidence intervals.

3. OCCURRENCE IN THE FOOD SUPPLY

No information on the occurrence of 1,1-dichloroethylene in food consumed in the United States was uncovered in our literature search.

4. OCCURRENCE IN AMBIENT AIR

Data on levels of 1,1-dichloroethylene in ambient air, taken from a report by Brodzinsky and Singh (1982), are presented in Table 15. Brodzinsky and Singh have compiled available published and unpublished atmospheric data on 1,1-dichloroethylene into a master file, and have subjected these data to statistical analysis. An assessment of the quality, reliability, and representativeness of the data was also performed. Each data point was then given a "quality code" based on either a quantitative assessment or on the authors' own experience and judgement. Quality codes were: 1 = Excellent; 2 = Good; 3 = Acceptable; 4 = Questionable; and Z = Unable to assign quality. These quality codes are further explained in Table 15.

Using data for quality codes 1-3 in Table 15, Brodzinsky and Singh (1982) calculated median concentrations of 20 ng/m^3 for urban/suburban areas and 14,000 ng/m^3 for source-dominated areas. No data for rural/remote areas were reported under quality codes 1-3; two data points for quality code 4 showed 0.0 ng/m^3 of 1,1-dichloroethylene in these areas. As might be expected, the majority of mean and median values reported were below 20 ng/m^3. The maximum value reported for quality codes 1-3 was 27,000 ng/m^3.

Table 15. Occurrence of 1,1-Dichloroethylene in Ambient Air[a]

Location	Number of data points	Number below detection limit	Mean (ng/m^3)	Standard deviation (ng/m^3)	Average of quality codes[b]	Minimum[c] (ng/m^3)	Median[c] (ng/m^3)	Maximum[c] (ng/m^3)	Date/time[d]	References
California	87	0	26	12	3.0	5.6	26	56	800702/1130 - 800712/1452	Singh et al. 1980
Colorado	85	28	26	84	3.0	0.0	5.6	560	800616/2012 - 800626/2359	Singh et al. 1980
Louisiana	7	0	4,400	280	2.0	4,400	4,400	4,400	770104/0747 - 770203/1020	Going and Spigarelli 1977
	11	7	120	0.0	4.0	120	120	120		Pellizzari et al. 1979
	5	0	27,000	290	2.0	27,000	27,000	27,000	770125/0800 - 770126/0824	Going and Spigarelli 1977
	10	9	20	0.0	4.0	20	20	20	770301 - 770301	Pellizzari 1978a
	25	25	0.0	0.0	4.0	0.0	0.0	0.0	770303/1150 - 770520/0900	Pellizzari et al. 1979
Michigan	2	0	24,000	24	2.0	24,000	0.0	24,000	770322/0949 - 770323/0941	Going and Spigarelli 1977
Missouri	78	1	14	6.8	3.0	0.0	14	26	800530/0911 - 800608/1614	Singh et al. 1980
New Jersey	46	46	0.0	0.0	4.0	0.0	0.0	0.0	790115 - 791229	Bozzelli et al. 1980
	48	48	0.0	0.0	4.0	0.0	0.0	0.0	790127 - 791229	Bozzelli et al. 1980
	50	50	0.0	0.0	4.0	0.0	0.0	0.0	790121 - 791229	Bozzelli et al. 1980
	29	29	0.0	0.0	4.0	0.0	0.0	0.0	760324/1247 - 760701/1625	Pellizzari et al. 1979
	54	54	0.0	0.0	4.0	0.0	0.0	0.0	790115 - 791229	Bozzelli et al. 1980
	23	23	0.0	0.0	4.0	0.0	0.0	0.0	790403 - 791024	Bozzelli et al. 1980
	1	1	0.0	0.0	4.0	0.0	0.0	0.0	770922/1030 - 770922/1130	Pellizzari and Bunch 1979
	42	42	0.0	0.0	4.0	0.0	0.0	0.0	790226 - 791229	Bozzelli et al. 1980
North Carolina	6	0	11,000	0.0	4.0	11,000	11,000	11,000	800600 - 800600	Wallace 1981
Oklahoma	2	2	0.0	0.0	4.0	0.0	0.0	0.0	770711/0600 - 770921/0900	Pellizzari 1978b
	1	1	0.0	0.0	4.0	0.0	0.0	0.0	770921/1400 - 770921/1700	Pellizzari 1978b
	2	2	0.0	0.0	4.0	0.0	0.0	0.0	770710/0355 - 770921/0900	Pellizzari 1978b
Pennsylvania	1	1	0.0	0.0	4.0	0.0	0.0	0.0	770821/1220 - 770821/1320	Pellizzari and Bunch 1979
	1	1	0.0	0.0	4.0	0.0	0.0	0.0	770822/1100 - 770822/1200	Pellizzari and Bunch 1979
	1	1	0.0	0.0	4.0	0.0	0.0	0.0	770819/1315 - 770819/1415	Pellizzari and Bunch 1979

Table 15. Occurrence of 1,1-Dichloroethylene in Ambient Air[a]
(continued)

Location	Number of data points	Number below detection limit	Mean (ng/m^3)	Standard deviation (ng/m^3)	Average of quality codes[b]	Minimum[c] (ng/m^3)	Median[c] (ng/m^3)	Maximum[c] (ng/m^3)	Date/time[d]	References
Texas	75	0	64	60	3.0	10	56	220	770628/0745 - 800524/1906	Singh et al. 1980
	15	15	0.0	0.0	4.0	0.0	0.0	0.0		Pellizzari et al. 1979
	1	0	520	0.0	4.0	520	0.0	520	760809/1348 - 760809/1555	Pellizzari et al. 1979
	11	0	48,000	0.0	4.0	48,000	48,000	48,000	800304 - 800304	Wallace 1981
	3	2	140	250	4.0	0.0	0.0	440	770622/0945 - 771020/1510	Pellizzari et al. 1979
Virginia	17	15	200	210	4.0	0.0	0.0	400	770929/1040 - 771028/0850	Pellizzari 1978b
West Virginia	4	4	0.0	0.0	4.0	0.0	0.0	0.0	770927/1202 - 771025/1147	Pellizzari 1978b
	6	6	0.0	0.0	4.0	0.0	0.0	0.0	770927/1115 - 771118/1310	Pellizzari 1978b
	6	6	0.0	0.0	4.0	0.0	0.0	0.0	770927/1349 - 771118/1241	Pellizzari 1978b
	6	6	0.0	0.0	4.0	0.0	0.0	0.0	770927/1400 - 771118/1250	Pellizzari 1978b
	2	2	0.0	0.0	4.0	0.0	0.0	0.0	771117/1235 - 771118/1210	Pellizzari 1978b
	4	4	0.0	0.0	4.0	0.0	0.0	0.0	770927/1020 - 771120/0930	Pellizzari 1978b

[a]Values originally reported as ppt were converted to ng/m^3 (1 ppt = 4.0 ng/m^3).

[b]Quality codes were assigned to the data as follows:

- 1: α = 1.25 (excellent)
- 2: α = 1.50 (good)
- 3: α = 2.00 (acceptable)
- 4: α > 2.00 (questionable)
- Z: unable to assign quality

where a true measurement Q lies between Q/α and αQ. Where two lines of data are listed, line 1 contains data for quality codes 1-3; line 2 for 4.

[c]These values do not necessarily represent the absolute minimum, median, and maximum values presented in the reports cited. Some of the data were preprocessed to facilitate the hand entry of the data into a computerized data base. Within a given reference, the data were averaged into daily averages for a given location, whenever possible. For locations where data was averaged, the minimum and maximum values reported above are generally higher and lower, respectively, than those reported in the references cited (Brodzinsky and Singh 1982; personal communication between Richard Brodzinsky, IBM, San Jose, California and Pauline Johnston, JRB Associates, April 7, 1983).

[d]Format is YYMMDD/TIME.

Source: Brodzinsky and Singh 1982

5. HUMAN EXPOSURE FROM DRINKING WATER, FOOD, AND AIR

Sections 2, 3, and 4 presented information on the occurrence of 1,1-dichloroethylene in drinking water, food, and air, respectively, focusing on estimates of the levels of 1,1-dichloroethylene found in those three media. This section uses the data presented there to estimate the extent of human exposure, both in terms of individual intake and the size of the affected population.

As mentioned in the Introduction, some individuals may be exposed to 1,1-dichloroethylene from sources other than the three considered here, notably in occupational settings and from the use of consumer products containing 1,1-dichloroethylene. This analysis, however, is limited to drinking water, food, and air, since these media are considered to be general sources common to all individuals. Even in limiting the analysis to these three sources, it must be recognized that individual exposure will vary widely based on many personal choices and several factors over which there is little control. Where one lives, works, and travels, what one eats, and physiologic characteristics related to age, sex, and health status can all profoundly affect daily exposure and intake. Individuals living in the same neighborhood or even in the same household can experience vastly different exposure patterns.

Unfortunately, data and methods to estimate exposure of identifiable population subgroups from all sources simultaneously have not yet been developed. To the extent possible, estimates are provided of the number of individuals exposed to each medium at various 1,1-dichloroethylene concentrations. For estimating intake, two specific subpopulations are considered: adult male and newborn formula-fed infant. The adult male is typically used for computing human intake when risk is extrapolated from animal models. Data for the newborn formula-fed infant are included because this subpopulation, as a result of differences in fluid consumption and respiratory rates, experiences a significantly different intake (on a body weight basis)* than the

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*For computing intake in units of mass/body weight/day, standard body weights of 70 kg for an adult male and 3.5 kg for a newborn are used. These are taken from the Report of the Task Group on Reference Man (ICRP 1975).

adult male, even though the amounts of 1,1-dichloroethylene present in the exposure media are the same for both groups. Generally, the intake from drinking water for the newborn formula-fed infant is substantially higher than that of the adult male, while the intake from air for the newborn formula-fed infant is lower.

No data were obtained on regional variations in the concentration of 1,1-dichloroethylene in drinking water. The highest concentrations are expected to occur near sites of production and use of 1,1-dichloroethylene.

5.1 DRINKING WATER INTAKE

5.1.1 Population Exposed

Estimates of the size of U.S. populations exposed to various 1,1-dichloroethylene levels in drinking water from public drinking water systems are presented in Tables 16-20. Table 14 shows the population exposed to 1,1-dichloroethylene from groundwater supplies at various concentration ranges; Table 17 shows the cumulative number of people exposed to 1,1-dichloroethylene exceeding various levels in groundwater supplies. Tables 18 and 19 provide similar population exposed information for surface water supplies. The cumulative population exposed to concentrations exceeding various levels from both sources are shown in Table 20. The values in these tables were obtained using Federal Reporting Data Systems data on populations served by primary water supply systems and the estimated number of these water systems that contain a given level of 1,1-dichloroethylene (see Section 2.4). An estimated 4,789,000 individuals (2.2% of the population of 214,419,000 using public water supplies) are exposed to levels of 1,1-dichloroethylene in drinking water at or above 0.2 ug/l, while 52,000 individuals (< 0.1%) are exposed to levels above 5 ug/l. It is estimated that no individuals are exposed to levels greater than 10 ug/l. Of the approximately 4.7 million people exposed to levels ranging from 0.2 to 5 ug/l, 2.4 million (52%) obtain water from surface water supplies. All exposure to 1,1-dichloroethylene in drinking water at levels above 5 ug/l is expected to be from groundwater sources.

As noted earlier, newborn formula-fed infants are a special subpopulation whose fluid consumption rate generally results in a higher intake on a body weight basis than adult males exposed to drinking water at the same contami-

nant level. To arrive at an estimate of the size of the infant population potentially exposed to 1,1-dichloroethylene from drinking water and the intake received by them, several assumptions were necessary.

Newborn infants are defined here as children up to 1 month old, corresponding to a body weight of 3.5 kg. The U.S. Bureau of the Census reported that 3,533,044 children less than 1 year of age lived in the United States in 1980 comprising 1.6% of the total 1980 U.S. population of 226,504,852 persons.* The percentage of newborn infants up to one month of age at a given point in time could be estimated as 1/12 of the number of infants under one year of age, or (1/12) x (1.6%) of the U.S. population. In the course of a year, however, all infants under one year of age, or 1.6% of the U.S. population, would have been under one month of age at some time. For the purposes of this report, the percentage of children in the U.S. under one year of age was used to represent all children who would have been under one month of age during a given year.

An estimated fluid intake level of 850 ml/day for the newborn infant was derived by Coniglio** based on information presented in the Report of the Task Group on Reference Man (ICRP 1975). The drinking water intake level of 2 liters per day used for estimating exposure for the adult male includes all fluid intake (tap water, coffee, juices, beer, etc). In the case of newborn infants, many obtain most if not all of their fluid from breast milk, which is deemed inappropriate to include in the estimate of drinking water intake. Martinez and Dodd (1983) have presented the results of a recent survey on milk feeding patterns of infants in the United States. Based on their data, it is estimated that at one month of age, 50% receive formula, 44% receive breast milk, and 6% receive breast milk with supplemental formula. (Less than 1% are estimated to receive cow's milk or evaporated milk.) No information was given on the amount of formula received by those breast-fed infants receiving supplemental formula, so it is assumed that at one month half of these infants

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*Personal communication between Catherine O'Brien, U.S. Bureau of the Census, and Pauline Johnston, JRB Associates, June 25, 1982.

**Personal communication between William Coniglio, Office of Drinking Water, U.S. Environmental Protection Agency, and Frank Letkiewicz, JRB Associates, January 1982.

receive the majority of their fluid from formula. No information was available on the amount of tap water consumed directly as water by one-month-old infants. Consumption of juice among newborns is considered negligible. It was, therefore, assumed that breast milk or formula constitute the predominant fluid sources for newborns infants. Based on the Martinez and Dodd (1983) data, it is estimated that 47% of the newborn infant population receive effectively all of their fluid from breast milk and, therefore, are not exposed to drinking water. The 53% that are formula-fed have drinking water as their source of fluid intake. It is therefore estimated that there are 1,818,000 formula-fed infants obtaining drinking water from public water supplies (214,419,000 x 0.016 x 0.53).

It should be noted that the population of infants exposed to 1,1-dichloroethylene in drinking water from formula feeding would increase with age up to approximately six months. Martinez and Dodd (1983) reported that, in 1981, 48% of newborn infants in the hospital received formula. Between the ages of 2-6 months, the percentage of infants receiving formula had increased to approximately 60-70% of the total infants surveyed. The percentage then declined to 14% by age 12 months. As the infants grew older, breast feeding and formula feeding were gradually replaced by feeding with cow's milk or evaporated milk. However, other sources of drinking water exposure (e.g., tap water, juices) are expected to come into greater use as the child ages.

Infant formula is available in three primary forms: ready-to-feed, liquid concentrate, and powder. Patzer* has provided information indicating that, over the first year of life, the average formula-fed infant will consume 53% of the total amount of water consumed from formula from the liquid concentrate, 38% from ready-to-feed, and 9% from powder. Insufficient information was available on processing techniques used to prepare ready-to-feed and liquid concentrate formulas to determine whether VOCs would be removed from the process water. In the absence of this information, it was assumed that little, if any, of the VOC present in the water would be removed. (A similar

*Personal communication between Emmons Patzer, Mead Johnson, Evansville, IN, and Corinne Macaluso, JRB Associates, June 9, 1983.

assumption is made for purchased beverages included in the drinking water intake for adults.)

According to Patzer*, 78% of the formula users sterilize the tap water added to the liquid concentrate and powder formulas. Glick** has indicated that some data are available suggesting that a 10-minute boiling time of one gallon of water removes 80-100% of VOC's present, and that the rapid boiling of about one quart followed by immediate removal from heating removes 50-80% of VOCs. In estimating the newborn formula-fed infant population exposed to various levels of 1,1-dichloroethylene from drinking water, the drinking water concentration is adjusted for the portion of infants whose water is boiled prior to adding to the formula.

The percentage of the original 1,1-dichloroethylene level in the water received by the formula-fed infant after boiling of the added water is calculated as follows (using the formula distribution by type provided by Patzer*, an assumption of no tap water added to the ready-to-feed, 50% dilution of the liquid concentrate, 100% tap water in the powder, and an assumption of 80% removal of 1,1-dichloroethylene by boiling tap water):

Ready-to-feed (38% of water, no VOC removed)	Liquid concentrate (53% of water, 50% with no VOC removed, 50% with 80% VOC removed)	Powder (9% of water, 80% of VOC removed)

$$(0.38)(1.0) + (0.53)(0.5)(1.0) + (0.53)(0.5)(0.2) + (0.09)(0.2) = 0.72$$

Therefore, it is estimated that 78% of formula-fed infants receive water with the equivalent of only 72% of the original VOC level in their water supplies while the remaining 22% of the formula-fed infants receive water at the level estimated to be present in their water supplies.

The population of newborn formula-fed infants exposed to the drinking water levels shown in Table 21 (and later in Table 24) has been adjusted to

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*Personal communication between Emmons Patzer, Mead Johnson, Evansville, IN, and Corinne Macaluso, JRB Associates, June 9, 1983.

**Personal communication between Edward Glick, Office of Drinking Water, U.S. Environmental Protection Agency, and Dave Taylor, consultant to JRB Associates, April 13, 1983.

account for the boiling of added water. The population of infants whose water is boiled (78%) is subtracted from the estimated population of newborn formula-fed infants associated with various drinking water concentrations prior to boiling (based on the data in Tables 16 and 18 and the assumptions described above). This population is then added to the population at an appropriate lower concentration. The lower concentration is calculated as the value of 72% of the midpoint of the original concentration range.

From data on the estimated populations exposed to various levels of 1,1-dichloroethylene in drinking water, it was estimated that 40,000 formula-fed infants are exposed to drinking water containing 1,1-dichloroethylene levels at or exceeding 0.2 ug/l, while 440 formula-fed infants are exposed to levels greater than 5 ug/l.

5.1.2 Daily Intake of 1,1-Dichloroethylene from Drinking Water

Daily intake levels of 1,1-dichloroethylene from drinking water were estimated using various exposure levels and the assumptions presented in Table 21. The data in the table suggest that the majority of the persons using public drinking water supplies would be exposed to intake levels below 0.0057 ug/kg/day for adults and 0.048 ug/kg/day for infants.

5.1.3 Population-Concentration and Population-Exposure Estimates

An indication of the overall exposure of the total population to 1,1-dichloroethylene can be obtained through the calculation of population-concentration values. These values are a summation of the individual levels of 1,1-dichloroethylene to which each member of the population is exposed. An explanation of the derivation of these values is presented in Appendix C. Population-concentration estimates for 1,1-dichloroethylene in drinking water were obtained using the values presented in Tables 16 and 18. The estimates are 1.2×10^6 ug/l x persons (best case), 1.3×10^7 ug/l x persons (mean best case), 5.3×10^7 ug/l x persons (mean worst case), and 6.4×10^7 ug/l x persons (worst case).

Assuming a consumption rate of 2 liters of water/day, population-exposure values of 2.4×10^6 ug/day x persons (best case), 2.6×10^7 ug/day x persons (mean best case), 1.1×10^8 ug/day x persons (mean worst case), and 1.3×10^8 ug/day x persons (worst case) were derived.

Table 16. Estimated Population (in Thousands) Exposed to 1,1-Dichloroethylene in Drinking Water at the Indicated Concentration Ranges from Groundwater Systems in Each Size Category[a]

System size (population served)	Number of people served in U.S. (thousands)	Population (thousands) exposed to concentrations (ug/l) of:			
		<0.2[b]	0.2-5	>5-10	>10
25-100	1,031	1,031.4	15.8	1.8	0.0
101-500	3,814	3,749.0	58.5	6.5	0.0
501-1,000	3,590	3,528.8	55.0	6.1	0.0
1,001-2,500	7,047	6,926.9	108.0	12.0	0.0
2,501-3,300	2,583	2,539.0	39.6	4.4	0.0
3,301-5,000	4,370	4,295.6	67.0	7.4	0.0
5,001-10,000	8,404	8,260.8	128.9	14.3	0.0
10,001-25,000	12,276	11,751.4	524.6	0.0	0.0
25,001-50,000	10,977	10,507.9	469.1	0.0	0.0
50,001-75,000	3,911	3,743.9	167.1	0.0	0.0
75,001-100,000	1,184	1,133.4	50.6	0.0	0.0
>100,000	14,286	13,675.5	610.5	0.0	0.0
Total	73,473	71,125.6	2,294.8	52.5	0.0

[a]Populations may not add to total due to rounding.

[b]Includes individuals exposed to no 1,1-dichloroethylene in drinking water and those exposed to levels < 0.2 ug/l.

Table 17. Estimated Cumulative Number of People (in Thousands) Exposed to 1,1-Dichloroethylene in Groundwater Systems Exceeding the Indicated Concentration (ug/l)

System size (population served)	Number of people served in U.S. (thousands)	Cumulative population (thousands) exposed to concentrations (ug/l) of:		
		≥ 0.2	> 5	> 10
25-100	1,031	17.6	1.8	0.0
101-500	3,814	65.0	6.5	0.0
501-1,000	3,590	61.2	6.1	0.0
1,001-2,500	7,047	120.1	12.0	0.0
2,501-3,300	2,583	44.0	4.4	0.0
3,301-5,000	4,370	74.4	7.4	0.0
5,001-10,000	8,404	143.2	14.3	0.0
10,001-25,000	12,276	524.6	0.0	0.0
25,001-50,000	10,977	469.1	0.0	0.0
50,001-75,000	3,911	167.1	0.0	0.0
75,001-100,000	1,184	50.6	0.0	0.0
>100,000	14,286	610.5	0.0	0.0
Total	73,473	2,347.3	52.5	0.0
Lower bound[a]		1,515.5	0.0	0.0
Upper bound[a]		3,179.2	154.9	0.0

[a]From 95% confidence intervals.

Table 18. Estimated Population (in Thousands) Exposed to 1,1-Dichloroethylene in Drinking Water at the Indicated Concentration Ranges from Surface Water Systems in Each Size Category

System size (population served)	Number of people served in U.S. (thousands)	Population (thousands) exposed to concentrations (ug/l) of:		
		< 0.2	0.2-5	> 5
25-100	86	86.0	0.0	0.0
101-500	690	690.0	0.0	0.0
501-1,000	1,051	1,051.0	0.0	0.0
1,001-2,500	3,295	3,295.0	0.0	0.0
2,501-3,300	1,445	1,445.0	0.0	0.0
3,301-5,000	3,096	3,096.0	0.0	0.0
5,001-10,000	6,763	6,763.0	0.0	0.0
10,001-25,000	15,595	15,289.2	305.8	0.0
25,001-50,000	13,945	13,671.6	273.4	0.0
50,001-75,000	9,483	9,297.1	185.9	0.0
75,001-100,000	7,131	6,991.2	139.8	0.0
>100,000	78,366	76,829.4	1,536.6	0.0
Total	140,946	138,504.4	2,441.6	0.0

[a]Populations may not add to total due to rounding.

[b]Includes individuals exposed to no 1,1-dichloroethylene in drinking water and those exposed to levels < 0.2 ug/l.

Table 19. Estimated Cumulative Number of People (in Thousands) Exposed to 1,1-Dichloroethylene from Surface Water Systems Exceeding the Indicated Concentration (ug/l)

System size (population served)	Number of people served in U.S. (thousands)	Cumulative population (thousands) exposed to concentrations (ug/l) of:	
		≥0.2	>5
25-100	86	0.0	0.0
101-500	690	0.0	0.0
501-1,000	1,051	0.0	0.0
1,001-2,500	3,295	0.0	0.0
2,501-3,300	1,445	0.0	0.0
3,301-5,000	3,096	0.0	0.0
5,001-10,000	6,763	0.0	0.0
10,001-25,000	15,595	305.8	0.0
25,001-50,000	13,945	273.4	0.0
50,001-75,000	9,483	185.9	0.0
75,001-100,000	7,131	139.8	0.0
>100,000	78,366	1,536.6	0.0
Total	140,946	2,441.6	0.0
Lower bound[a]		0.0	0.0
Upper bound[a]		5,711.0	0.0

[a]From 95% confidence intervals.

Table 20. Total Estimated Cumulative Population (in Thousands) Exposed to 1,1-Dichloroethylene in Drinking Water Exceeding the Indicated Concentration

System type	Number of people served in U.S. (thousands)	Cumulative population (thousands) exposed to concentrations (ug/l) of:		
		≥ 0.2	> 5	> 10
Groundwater	73,473.	2,347	52	0
Surface water	140,946	2,442	0	0
Total	214,419	4,789	52	0
(% of total)	(100%)	(2.2%)	(<0.1%)	(0.0%)

Table 21. Estimated Drinking Water Intake of 1,1-Dichloroethylene by Adults and Formula-Fed Infants

Exposure level (ug/l)	Persons using supplies exposed to indicated levels				Intake (ug/kg/day)	
	Population	% of Total population	Formula-fed infants	% of Formula-fed infants	Adult	Formula-fed infant
≥0.2	4,789,000	2.2%	40,000	2.2%	≥0.0057	≥0.048
>5.0	52,000	< 0.1%	440	< 0.1%	>0.14	>1.2
>10	0	0.0%	0	0.0%	>0.29	>2.4

Assumptions: 70-kg man, 3.5-kg infant; 2 liters of water/day (man), 0.85 liters of water/day (formula-fed infant).

5.2 DIETARY INTAKE

No data were obtained on levels of 1,1-dichloroethylene in foods. Therefore, the intake of 1,1-dichloroethylene from the diet could not be estimated.

5.3 RESPIRATORY INTAKE

Exposure to 1,1-dichloroethylene in the atmosphere varies from one location to another. High levels, averaging greater than 20,000 ng/m^3 (20 ug/m^3), have been detected in several areas. Normal levels, however, are lower. Using the data for quality codes 1-3 presented in Table 15, Brodzinsky and Singh (1982) calculated median air levels of 1,1-dichloroethylene for urban/suburban areas and source dominated areas of 20 ng/m^3 (0.020 ug/m^3) and 14,000 ng/m^3 (14 ug/m^3), respectively. Two data points for 1,1-dichloroethylene in rural/remote areas showed 0.0 ng/m^3 (quality code 4). The highest level of 1,1-dichloroethylene in the atmosphere reported under quality codes 1-3 was 27,000 ng/m^3 (27 ug/m^3) (Going and Spigarelli 1977 cited in Brodzinsky and Singh 1982).

The monitoring data available are not sufficient to determine regional variations in exposure levels for 1,1-dichloroethylene. However, urban and industrial areas appear to contain higher levels, as expected.

The daily respiratory intake of 1,1-dichloroethylene from air was estimated using the assumptions presented in Table 22 and the median and maximum levels for 1,1-dichloroethylene reported above. The estimates in Table 22 indicate that the daily 1,1-dichloroethylene intake from air for adults in source dominated areas is approximately 4.6 ug/kg/day. The intake calculated using the maximum level reported is 8.9 ug/kg/day. The values presented do not account for variances in individual exposure or uncertainties in the assumptions used to estimate exposure.

Table 22. Estimated Respiratory Intake of 1,1-Dichloroethylene by Infants and Adults

Exposure (ug/m^3)	Intake (ug/kg/day)	
	Adult	Infant
Rural/remote (0.0)	0.0	0.0
Urban/suburban (0.020)	0.0066	0.0046
Source dominated (14)	4.6	3.2
Maximum (27)	8.9	6.2

Assumptions: 70-kg man, 3.5-kg infant; 23 m^3 of air inhaled/day (man), 0.8 m^3 of air inhaled/day (infant) (ICRP 1975).

5.4 RELATIVE SOURCE CONTRIBUTION

This section of the report considers the relative contribution of drinking water and ambient air to total human exposure to 1,1-dichloroethylene from these two sources. (Since no data were obtained on levels of 1,1-dichloroethylene in foods in the United States, the contribution of 1,1-dichloroethylene in the diet to total 1,1-dichloroethylene exposure could not be assessed.) The data presented here indicate the potential total exposure to 1,1-dichloroethylene which could occur if a population was exposed to specific combinations of 1,1-dichloroethylene concentrations in drinking water and ambient air.

Table 23 presents a general view of the total amount of 1,1-dichloroethylene received by an adult male from air and drinking water. Table 24 presents similar conditions for a formula-fed infant. Four separate exposure levels in air and four exposure levels in drinking water are shown in the tables. The data presented represent possible exposures based on the occurrence data in Sections 2 through 4 and the estimated intakes in Sections 5.1 through 5.3.

Brodzinsky and Singh (1982) calculated a median urban/suburban air level of 1,1-dichloroethylene of 0.020 ug/m^3 based on air monitoring data (Section 4). Assuming an air level of 0.020 ug/m^3, drinking water would be the predominant source of 1,1-dichloroethylene exposure in the adult male at drinking water levels above 0.2 ug/l. However, for formula-fed infants exposed to air levels of 0.020 ug/m^3, intake of 1,1-dichloroethylene from drinking water is estimated to be the predominant source of exposure at levels above 0.02 ug/l. An accurate assessment of the number of individuals for which drinking water is the predominant source of exposure cannot be determined from the data since specific locations containing high concentrations of 1,1-dichloroethylene in drinking water and low concentrations of 1,1-dichloroethylene in ambient air and food are unknown.

The data presented have been selected from an infinite number of possible combinations of exposure from each of the two sources. The actual exposures encountered would represent some finite subset of this infinite series of combinations. Whether exposure occurs at any specific combination of levels is not known; nor is it possible to determine the number of persons that would be exposed to 1,1-dichloroethylene at any of the combined exposure levels.

The relative source contribution data are based on estimated intake and do not account for a possible differential absorption rate for 1,1-dichloroethylene by route of exposure. The relative dose received may vary from the relative intake. In addition, the relative effects of the chemical on the body may vary by different routes of exposure.

Table 23. Estimated Intake of 1,1-Dichloroethylene from the Environment by Adult Males in ug/kg/day (% from Drinking Water)

Concentration in drinking water (ug/l)	Concentration in air			
	Rural/remote (0.0 ug/m^3)	Urban/suburban (0.020 ug/m^3)	Source dominated (14 ug/m^3)	Maximum (27 ug/m^3)
0	0.0 (--)	0.0066 (0%)	4.6 (0%)	8.9 (0%)
0.2[a]	0.0057 (100%)	0.012 (48%)	4.6 (0.1%)	8.9 (0.06%)
5.0[b]	0.14 (100%)	0.15 (93%)	4.7 (3.0%)	9.0 (1.6%)
10[c]	0.29 (100%)	0.30 (97%)	4.9 (5.9%)	9.2 (3.2%)

Intake from each source (see Sections 5.1-5.3):

Water: 0.2 ug/l: 0.0057 ug/kg/day
5.0 ug/l: 0.14 ug/kg/day
10 ug/l: 0.29 ug/kg/day

Air: 0.0 ug/m^3: 0.0 ug/kg/day
0.020 ug/m^3: 0.0066 ug/kg/day
14 ug/m^3: 4.6 ug/kg/day
27 ug/m^3: 8.9 ug/kg/day

Food: Not included

[a] 4,789,000 individuals using public drinking water systems are estimated to be exposed to levels $\geq$ 0.2 ug/l (2.2% of population using public water supplies).

[b] 52,000 individuals using public drinking water systems are estimated to be exposed to levels > 5.0 ug/l (< 0.1% of population using public water supplies).

[c] No individuals using public drinking water systems are estimated to be exposed to levels > 10 ug/l.

Table 24. Estimated Intake of 1,1-Dichloroethylene from the Environment by Newborn Formula-Fed Infants in ug/kg/day (% from Drinking Water)

Concentration in drinking water (ug/l)	Concentration in air			
	Rural/remote (0.0 ug/m^3)	Urban/suburban (0.020 ug/m^3)	Source dominated (14 ug/m^3)	Maximum (27 ug/m^3)
0	0.0 (--)	0.0046 (0%)	3.2 (0%)	6.2 (0%)
0.2[a]	0.048 (100%)	0.053 (91%)	3.2 (1.5%)	6.2 (0.8%)
5.0[b]	1.2 (100%)	1.2 (100%)	4.4 (27%)	7.4 (16%)
10[c]	2.4 (100%)	2.4 (100%)	5.6 (43%)	8.6 (28%)

Intake from each source (see Sections 5.1-5.3):

Water:
- 0.2 ug/l: 0.048 ug/kg/day
- 5.0 ug/l: 1.2 ug/kg/day
- 10 ug/l: 2.4 ug/kg/day

Air:
- 0.0 ug/m^3: 0.0 ug/kg/day
- 0.020 ug/m^3: 0.0046 ug/kg/day
- 14 ug/m^3: 3.2 ug/kg/day
- 27 ug/m^3: 6.2 ug/kg/day

Food: Negligible

[a] 40,000 formula-fed infants using public drinking water systems are expected to be exposed to levels > 0.2 ug/l (2.2% of formula-fed infant population using public water supplies).

[b] 440 formula-fed infants using public drinking water systems are expected to be exposed to levels > 5.0 ug/l (< 0.1% of formula-fed infant population using public water supplies).

[c] No formula-fed infants using public drinking water systems are expected to be exposed to levels > 10 ug/l.

1,1-Dichloroethylene
Occurrence REFERENCES

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APPENDIX A

Methodology for Estimating the National Occurrence of Volatile Synthetic Organic Chemicals in Public Drinking Water Supplies and the Size of the Exposed Population

The U.S. Environmental Protection Agency (EPA) is currently considering the proposal of national revised primary drinking water regulations under the Safe Drinking Water Act, as well as non-federal regulatory approaches, to limit human exposure to high levels of certain volatile synthetic organic chemicals (VOCs) that have been detected in drinking water (Advanced Notice of Proposed Rulemaking, 47 FR 9350, March 4, 1982). The specific VOCs of immediate interest to EPA are:

- Trichloroethylene
- Tetrachloroethylene
- Carbon tetrachloride
- 1,1,1-Trichloroethane
- 1,2-Dichloroethane
- Vinyl chloride
- Dichloromethane
- Benzene
- Chlorobenzene
- Dichlorobenzene(s)
- Trichlorobenzene(s)
- 1,1-Dichloroethylene
- 1,2-Dichloroethylene (cis and trans)

The objective of the analysis of the occurrence of the VOCs listed above is to support EPA's consideration of the need and alternatives for controlling VOCs in public water supplies in two principal areas:

- As input to the health risk assessments for the VOCs, the analysis provides estimates of the number of individuals in the United States exposed to various levels of VOCs in drinking water from public water supplies.

- As input to the assessment of the economic impact of the regulatory and treatment alternatives being considered, the analysis provides estimates of the number of public water supplies of various source (i.e., groundwater and surface water) and size (based on population served) categories having VOCs present, and the distribution of VOC levels in those water supplies.

The methodology for preparing these estimates involved the creation of a data base drawing from the results of several Federal surveys on the measured occurrence of the VOCs in public water supplies as a function of water source and supply size. Statistical models were then used to extrapolate from the observed frequency of occurrence of the VOCs in the supplies sampled in the Federal surveys to the universe of public water supplies having similar source and size characteristics. A separate report has been prepared for each of the VOCs listed. Appendix A is included in each report to provide detail on the sources of data and the methodology used to obtain these estimates. Some specifics presented in Appendix A may not be applicable to the VOC that is the subject of this report. Appendix B provides additional detail on the selection of an appropriate model for estimating the national occurrence of the VOC that is addressed in this report.

A.1 SOURCES OF DATA

A.1.1 Number of Public Drinking Water Supplies in the United States and Size of Populations Served

It is currently estimated that there are approximately 60,000 public drinking water supplies in the United States serving approximately 214 million people. Table A-1 summarizes the estimated number of surface water and groundwater systems of various sizes and the associated populations served by them. These data, which correspond to the "FY 82 Characterization of the Water Supply Industry" presented by Kuzmack (1983), as updated by Schnare*, were derived from the Federal Reporting Data Systems (FRDS) for FY 1982 (FRDS 1983).

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*Personal communication between David Schnare, Office of Drinking Water, U.S. Environmental Protection Agency, and Frank Letkiewicz, JRB Associates, May 25, 1983.

Table A-1. Number of Systems and Population Served
by Primary Water Supply Source
(By Population Category)

System size (Population served)		Surface			Groundwater		
		No. of systems	Population (thousands)	Average population served	No. of systems	Population (thousands)	Average population served
Very small	25-100	1,525	86	56	19,125	1,031	54
	101-500	2,412	690	286	15,674	3,814	243
Small	501-1,000	1,377	1,051	763	4,877	3,590	736
	1,001-2,500	1,945	3,295	1,700	4,400	7,047	1,600
	2,501-3,300	495	1,445	2,900	891	2,583	2,900
Medium	3,301-5,000	749	3,096	4,100	1,065	4,370	4,100
	5,001-10,000	930	6,763	7,300	1,168	8,404	7,200
Large	10,001-25,000	915[a]	15,595[b]	17,000	835[a]	12,276[b]	15,000
	25,001-50,000	400[a]	13,945[b]	35,000	290[a]	10,977[b]	38,000
	50,001-75,000	155	9,483	61,000	64	3,911	61,000
	75,001-100,000	82	7,131	87,000	14	1,184	85,000
Very large	>100,000	217	78,366	360,000	55	14,286	260,000
TOTALS[c]:		11,202	140,948		48,458	73,475	

[a]Kuzmack 1983, as updated by David Schnare, Office of Drinking Water, U.S. Environmental Protection Agency, in a personal communication with Frank Letkiewicz, JRB Associates, May 25, 1983.

[b]Estimated by JRB Associates (see Table A-2).

[c]Populations do not add to total due to rounding.

Source: FRDS 1983 (except as noted).

It should be noted that FRDS (1983) does not provide a breakdown of the number of systems or of the population served for the 10,001-25,000 and 25,001-50,000 size categories, but rather for 10,001-50,000 as a single category. The estimated number of systems in the 10,001-25,000 and 25,001-50,000 size categories, as presented in Kuzmack (1983), were estimated by Dr. David Schnare of the Office of Program Development and Evaluation, EPA Office of Drinking Water from additional FRDS data. (Data for these additional categories are needed for the economic impact analysis.) The population served by systems in these size categories were estimated by JRB as shown in Table A-2.

Table A-2. Analysis for Estimating the Population Served by Surface Water and Groundwater Supplies in the 10,001-25,000 and 25,001-50,000 Population Size Categories

System size (population served)	Source		Total
	Surface water	Groundwater	
10,001-25,000	w	x	27,870[a]
25,001-50,000	y	z	24,920[a]
Total	29,540[b]	23,250[b]	52,790

[a]Estimated total population for surface water and groundwater provided by Kuzmack (1983).

[b]Population served by surface water and groundwater supplies in the 10,001-50,000 category from FRDS (1983).

$$w = \frac{29,540 \times 27,870}{52,790} = 15,595$$

$$x = \frac{23,250 \times 27,870}{52,790} = 12,276$$

$$y = \frac{29,540 \times 24,920}{52,790} = 13,945$$

$$z = \frac{23,250 \times 24,920}{52,790} = 10,977$$

A.1.2 Data on Measured Occurrence of VOCs in Public Water Supplies

There are three primary sources of information available on the occurrence of VOCs in drinking water supplies that were considered for use in preparing the national projections:

- Federal surveys,
- State data, and
- Miscellaneous data.

Only the Federal survey data were ultimately used for the national projections. While a substantial amount of state and miscellaneous published data were available for some of the VOCs examined, these data usually did not provide adequate details on the water source, size of the population served, or type of sample taken (raw, finished, or distribution), which precluded incorporating them into the analysis. Furthermore, there was usually no detailed information available on the sampling and analysis methodology used to obtain the data, which precluded their being subjected to a quality assurance review (performed as a separate task) (JRB Associates 1982). In addition, much of the state and miscellaneous data appeared to have been obtained in response to spills, citizen complaints, or other evidence of contamination and, therefore, were not considered to be representative data for preparing the national projections. While the state and miscellaneous published data were not used for deriving the national projections, these data are presented and discussed in the individual VOC occurrence reports.

The Federal survey data generally provided the information on water source, population served, and sample type studied that was necessary to perform the analyses in this report. These surveys also provided sufficient information on the sampling and analysis methods to be subjected to the quality assurance review. The following six Federal surveys were used for the national projections:

- National Organics Reconnaissance Survey (NORS)

  The National Organics Reconnaissance Survey (NORS) was conducted early in 1975 for the purpose of determining levels of four trihalomethanes (chloroform, bromodichloromethane, dibromochloromethane, and bromoform), carbon tetrachloride, and 1,2-dichloroethane in finished water supplies from 80 cities across the country (Symons et al. 1975). A population base of 36 million individuals was covered during

the study. Analysis of samples was performed by the Water Supply Research Laboratory of EPA in Cincinnati using purge and trap gas chromatography with an electrolytic conductivity detector.

- National Organic Monitoring Survey (NOMS)

The National Organic Monitoring Survey (NOMS) was conducted to determine the frequency of occurrence of specific organic chemicals in finished water supplies of 113 cities across the country (Brass et al. 1977). Among the chemicals surveyed were trihalomethanes, 1,2-dichloroethane, carbon tetrachloride, trichloroethylene, benzene, vinyl chloride, dichlorobenzene, and trichlorobenzene. Data from three phases (referred to as NOMS I, NOMS II, and NOMS III) of the study were collected over an eleven month period (March 1976 to January 1977) to reflect any long-term or seasonal variations. The analytical treatment of the samples was similar to that for the NORS samples. (Gas chromatography/mass spectrometry analyses were done for benzene.)

- National Screening Program for Organics In Drinking Water (NSP)

SRI International conducted a study from June 1977 to March 1981, entitled National Screening Program for Organics in Drinking Water (NSP), in which raw and finished drinking water samples were collected from 166 water facilities located in 33 states (Boland 1981). The compounds sampled were 23 halocarbons, 6 aromatics, and 22 pesticides, phenols, and acids. The methods used for analysis included gas chromatography with electron capture detection for purgeable halocarbons and the base/neutral extraction fraction, and gas chromatography with flame ionization detection for purgeable aromatics.

- Community Water Supply Survey (CWSS)

The Community Water Supply Survey (CWSS) examined 106 surface water supplies, 330 groundwater supplies, and 16 supplies with mixed water or purchased sources in 1978. Trihalomethanes and other volatile organic chemicals, including carbon tetrachloride, chlorobenzene, 1,2-dichloroethane, cis- and trans-1,2-dichloroethylene, tetrachloroethylene, 1,1,1-trichloroethane, trichloroethylene, benzene, toluene, and xylenes were measured. One to five samples were collected from each system, including raw, finished, and/or distribution water. Gas chromatography with an electrolytic conductivity detector was used for halocarbons and a flame ionization detector for aromatic analyses.

- Rural Water Survey (RWS)

The Rural Water Survey, conducted in 1978, was carried out in response to Section 3 of the Safe Drinking Water Act, which mandated that EPA "conduct a survey of the quantity, quality, and availability of rural drinking water supplies." Samples collected from 855 households in rural areas from across the United States were analyzed for trihalomethanes and for carbon tetrachloride, 1,2-dichloroethane, cis- and trans-1,2-dichloroethylene, tetrachloroethylene, 1,1,1-trichloroethane, and trichloroethylene using gas chromatography with an electrolytic conductivity detector. The majority of the 855 samples were

from households using private wells or small supplies serving fewer than 25 people. Using information provided by Dr. Bruce Brower at Cornell University, Department of Rural Sociology, it was determined that the RWS file had data for up to 207 groundwater and up to 45 surface water supplies serving more than 25 people.

- Groundwater Supply Survey (GWSS)

  The Groundwater Supply Survey (GWSS), conducted between December 1980 and December 1981, involved the national sampling of 945 public water supply systems using groundwater sources for 5 trihalomethanes and 29 other organic chemicals. Analyses were done using purge and trap gas chromatography with an electrolytic conductivity detector for halocarbons and a non-destructive photoionization detector for aromatics. There were 466 randomly selected supplies and 479 selected with state and EPA regional input based on the likelihood of finding some VOC contamination.

Table A-3 indicates which of the VOCs listed earlier were examined in each of the six Federal surveys used for the national projections. (Additional details on those surveys providing data on the VOCs addressed in this report are presented in Chapter 2.)

Table A-3. VOCs of Interest Examined in the Six Federal Surveys Used for National Projections

	NORS	NOMS	NSP	CWSS	RWS	GWSS
Trichloroethylene		X	X	X	X	X
Tetrachloroethylene		X	X	X	X	X
Carbon tetrachloride	X	X	X	X	X	X
1,1,1-Trichloroethane		X	X	X	X	X
1,2-Dichloroethane	X	X	X	X	X	X
Vinyl chloride		X	X			X
Dichloromethane		X	X			X[a]
Benzene		X	X	X		X
Chlorobenzene			X	X		X
Dichlorobenzene(s)		X	X			X
Trichlorobenzene(s)		X	X			
1,1-Dichloroethylene			X			X
1,2-Dichloroethylene (cis and trans)			X	X	X	X

[a]Dichloromethane data for the GWSS were not used due to a sample contamination problem.

A.2 GENERAL METHODOLOGY

A.2.1 Development of Survey Files

To facilitate the handling of data for preparing the national projections, suitable machine-readable files were developed for each of the six Federal surveys. JRB was provided access to existing computer files for the CWSS, RWS, and GWSS through the EPA Office of Drinking Water's Technical Support Division (ODW/TSD) in Cincinnati, Ohio. JRB used the published results of the NORS (Symons et al. 1975) and the NSP (Boland 1981), and printed results for the NOMS provided by ODW/TSD to create machine readable files of those surveys. Three separate files were created for NOMS, one for each of the three phases. (In effect, NOMS I, II, and III were treated as three separate surveys.) The final files for all chemicals were in SAS format. All computer efforts for this project utilized EPA's NCC-IBM (IBM 370) computer at Research Triangle Park, North Carolina.

It was necessary to prepare working versions of each survey file containing the following minimum information for each of the sampled water supplies:

- Location of the supply (state and city);
- Population served by the supply;
- Water source (groundwater, surface water, mixed, purchased, etc.); and
- A single concentration value for each VOC sampled.

With the exception of the RWS and NSP, the existing files and printed sources provided adequate information on the location of the supply sampled. The RWS design involved the collection of drinking water samples from households in rural areas of the United States. With the assistance of Dr. Bruce Brower at Cornell University's Department of Rural Sociology (responsible for the preparation of a detailed analysis of RWS results on inorganics, pesticides, and other parameters), it was possible to determine which of the 855 households for which VOC analyses were done obtained water from public water supplies. However, because of confidentiality restrictions on the RWS data, it was only possible to determine the location of the household and the public water supplies sampled at the state and county level, but not at the city or town level.

For NSP, the locations were not reported in Boland (1981); however, the Office of Drinking Water, Science and Technology Branch (ODW/STB) was able to provide copies of data sheets on the supplies sampled in NSP which provided information on location.

The existing files of the CWSS and GWSS each provided data on the size of the population served by the supplies sampled. For NORS, it was necessary to estimate the population served using information presented in Symons et al. (1975) on the location of the supply and recent population data for those areas from other sources. It should be noted that most of the supplies sampled in the NORS fall into the large and very large size categories. Consequently, errors in the precise number used for persons served by those systems would not alter their classification or their impact on the national projections.

For NOMS, data on the populations served by supplies were provided by ODW/TSD. In the case of NSP, the population served by each supply was not reported in Boland (1981). Again, those data were obtained from the data sheets provided by ODW/STB. (There were three NSP locations for which the population was not specified.)

For RWS, data on the size of the population served by supplies were not collected. However, data were obtained on the number of service connections for each supply. With the assistance of Dr. Bruce Brower at Cornell University, it was possible to estimate the population served by each supply from the service connection data and data on the average number of individuals per household observed in the survey (3.034).

The identification of water source as groundwater, surface water, mixed, etc. was clearly designated in the CWSS, RWS, and GWSS files. For NORS, the source was determined from the descriptive information in Symons et al. (1975). For NOMS, source designations were provided by ODW/TSD. For NSP, source information was given on the data sheets provided by ODW/STB.

Some public water supplies use a mixture of groundwater and surface water sources. Although these "mixed" supplies are counted as groundwater or surface water among the 60,000 supplies in FRDS, based on the predominant source used, such supplies were excluded from the survey data for developing the national projections because the predominant source was rarely indicated in

the survey file. Similarly, water supplies identified as purchasing water from another, usually unspecified, supply were excluded from the survey data for the national projections.

A.2.2 Computing Average Values for VOCs in Each Survey

In order to prepare the national projections, it was necessary that a single value be obtained for each VOC in each supply sampled. This requirement presented certain difficulties for several of the files where multiple sample results were reported for the supplies. NORS and NSP provided data on raw (i.e., untreated water sampled at the supply) and finished (i.e., treated water sampled at the supply) samples; CWSS provided data on raw, finished, and distribution (i.e., water sampled at a user's faucet) samples; NOMS and GWSS used finished water only; and RWS used distribution water only. In order that the national projections be derived from data on drinking water samples most representative of what people actually consume, all data on raw water were excluded from this analysis. Initially, consideration was given to excluding finished water sample data in the CWSS for supplies also having distribution samples. However, ODW/TSD staff indicated that inconsistencies in coding data for the CWSS resulted in some errors in designating water as finished or distribution. Therefore, all CWSS finished and distribution samples were included in the analysis as being equally representative of the water to which consumers are exposed.

The NORS, NOMS, and GWSS provided a single analytical result for each VOC in finished water. For NSP and RWS, there was generally only a single value reported for each VOC, although a few systems had multiple samples. In CWSS, most supplies had multiple finished and/or distribution samples for each VOC. Where multiple samples occurred, a single "supply value" was computed for each VOC using the following rules:

- If positive values were reported for all samples, the supply value was computed as the arithmetic mean.
- If both positive values and values below the minimum quantifiable concentration were reported, the supply value was computed as the mean of the positive values and the minimum quantifiable concentration values.

- If values below the minimum quantifiable concentration were reported for all samples, the supply value was computed as the mean of the minimum quantifiable limits reported for each sample. (These means were recorded as "negative" values to indicate that the VOC was not observed.)

Computing a single value for supplies where the value for one or more of the samples was reported to be below the minimum quantifiable concentration was problematic. These "negative" values imply that the analyte in question may or may not be present and, if present, is so at a concentration below that measurable by the analytical method. In other words, the actual value is greater than or equal to zero and less than the minimum quantifiable concentration.

Where a supply was reported to have samples with both positive and negative values, two major alternatives were considered for treating the negative values. The first was to ignore or eliminate the negative values from the computation of the mean. This was considered unacceptable because it implies that the negative data are less valid than the positive data, which is not the case. This alternative would also necessarily result in a higher average value for that system than would be the case if the actual value for the negative data were known.

The second alternative was to assign the negative data a specific value for computing the supply average. Three possibilities were considered: 0, the minimum quantifiable concentration, and the midpoint between 0 and the minimum quantifiable concentration. Assigning the negative samples a value equal to the minimum quantifiable concentration was selected since this gives the most conservative estimate of the supply value. That is, if the analyte was in fact present, the maximum possible concentration it could have in that sample would be approximately (actually slightly less than) the minimum quantifiable concentration. For example, if a supply was reported to have one sample with a VOC present at 0.3 ug/l and another sample in which the VOC was not observed at a minimum quantifiable concentration of 0.1 ug/l, a supply value of 0.2 ug/l was recorded in the working file. Using the minimum quantifiable concentration with other actual positive values to compute the mean results is the most conservative estimate of the supply value utilizing all sample data.

The treatment of supplies having only negative values reported derives from the treatment of those with negatives and positives described above. If,

for example, a VOC was not observed in two samples from a given system at minimum quantifiable concentrations of 0.1 ug/l and 0.3 ug/l, respectively, the system value retained in the working file was a "negative" 0.2 ug/l. That is, the VOC was not observed, but if it had been present in both samples, the maximum possible average concentration for that supply would have been 0.2 ug/l.

A.2.3 Combining Data from the Federal Surveys

Once the multiple samples for each VOC were averaged to obtain a single value for each supply sampled, tables on the frequency of occurrence of each chemical were prepared for each survey as presented in Sections 2.2.1 and 2.3.1. In addition, the mean, median, range, and other statistics were computed for the positive values in each survey.

The next step in developing the national projections was to combine the results of all of the surveys together. In doing this, it was necessary to identify those supplies that had been sampled in more than one survey and compute an average supply value for each VOC. (The rules for averaging samples within a survey described in Section A.2.2 applied to computing averages across surveys.) It should be noted that supplies sampled in the RWS could not be matched against the other surveys since the RWS locations could only be determined at the state and county level, as previously described.

Table A-4 presents a list of those systems which were duplicated across the Federal surveys. When a system was sampled in two or more surveys, the population used for that system in the combined survey file was the one reported in the most recent survey, represented by the following chronological order (most recent first): GWSS, NSP, CWSS, NOMS, and NORS.

Table A-4. Systems Sampled in More Than One Survey

Location	Source	Surveys in which the system was sampled
Tucson, AZ	G	GWSS, NORS
Fresno, CA	G	GWSS, NOMS
Jacksonville, FL	G	NOMS, NORS
Idaho Falls, ID	G	GWSS, NORS
Rockford, IL	G	GWSS, NOMS
Campbellsburg, IN	G	GWSS, CWSS
South Bend, IN	G	GWSS, NSP
Baton Rouge, LA	G	NSP, NOMS
Hammond, LA	G	GWSS, CWSS
Lafayette, LA	G	GWSS, CWSS
Senath, MO	G	GWSS, CWSS
Webb City, MO	G	GWSS, CWSS
Greenville, MS	G	NOMS, NORS
Kearney, NE	G	GWSS, CWSS
Lincoln, NE	G	NOMS, NORS
Alburquerque, NM	G	NOMS, NORS
Baldwinsville, NY	G	GWSS, CWSS
Dayton, OH	G	NSP, NOMS, NORS
Aliquippa, PA	G	GWSS, CWSS
Sioux Falls, SD	G	GWSS, NOMS
Memphis, TN	G	NOMS, NORS
San Antonio, TX	G	GWSS, NOMS, NORS
Provo, UT	G	CWSS, NOMS
Marysville, WA	G	GWSS, CWSS
Spokane, WA	G	GWSS, NSP, NOMS
Chippewa Falls, WI	G	GWSS, CWSS
Madison, WI	G	NSP, NOMS
Powell, WY	G	GWSS, CWSS
Birmingham, AL	S	NSP, NOMS
Camden, AR	S	NOMS, NORS
Little Rock, AR	S	NSP, NOMS
Phoenix, AZ	S	NSP, NORS
Concord, CA	S	NOMS, NORS

Table A-4. Systems Sampled in More Than One Survey
(continued)

Location	Source	Surveys in which the system was sampled
Los Angeles, CA	S	NOMS, NORS
Oakland, CA	S	NSP, NOMS
Sacramento, CA	S	NSP, NOMS
San Diego, CA	S	NOMS, NORS
San Francisco, CA	S	NOMS, NORS
Denver, CO	S	NSP, NOMS, NORS
Pueblo, CO	S	NOMS, NORS
New Haven, CT	S	NSP, NOMS
Waterbury, CT	S	NOMS, NORS
Washington, DC	S	NSP, NOMS, NORS
Atlanta, GA	S	NSP, NOMS, NORS
Davenport, IA	S	NSP, NOMS, NORS
Chicago, IL	S	NSP, NOMS, NORS
Fort Wayne, IN	S	NSP, NOMS
Indianapolis, IN	S	NSP, NOMS, NORS
Whiting, IN	S	NOMS, NORS
Topeka, KS	S	NSP, NOMS, NORS
Louisville, KY	S	NSP, NOMS
Boston, MA	S	NSP, NOMS, NORS
Lawrence, MA	S	NSP, NORS
Baltimore, MD	S	NSP, NOMS, NORS
Portland, ME	S	NSP, NOMS
Detroit, MI	S	NSP, NOMS, NORS
Grand Rapids, MI	S	NSP, NOMS
Mount Clemens, MI	S	NOMS, NORS
St. Paul, MN	S	NOMS, NORS
Cape Girardeau, MO	S	NOMS, NORS
Kansas City, MO	S	NSP, NOMS, NORS
St. Louis, MO	S	NSP, NORS
Jackson, MS	S	NSP, NOMS
Charlotte, NC	S	NSP, NOMS
Bismarck, ND	S	CWSS, NOMS

Table A-4. Systems Sampled in More Than One Survey
(continued)

Location	Source	Surveys in which the system was sampled
Omaha, NE	S	NSP, NOMS
Manchester, NH	S	NSP, NOMS
Elizabeth, NJ	S	NSP, NOMS
Passaic, NJ	S	NSP, NOMS, NORS
Buffalo, NY	S	NOMS, NORS
Poughkeepsie, NY	S	CWSS, NOMS
Cincinnati, OH	S	NSP, NORS
Cleveland, OH	S	NSP, NOMS, NORS
Columbus, OH	S	NSP, NOMS, NORS
Toledo, OH	S	NSP, NOMS
Oklahoma City, OK	S	NSP, NOMS, NORS
Tulsa, OK	S	NSP, NOMS
Corvallis, OR	S	NSP, CWSS, NOMS, NORS
Eugene, OR	S	NSP, CWSS, NOMS
Portland, OR	S	NSP, NOMS
Harrisburg, PA	S	NSP, CWSS
Philadelphia, PA	S	NSP, NORS
Pittsburgh, PA	S	NSP, NORS
Newport, RI	S	NOMS, NORS
Providence, RI	S	NSP, NOMS
Charleston, SC	S	NSP, NOMS, NORS
Huron, SD	S	NOMS, NORS
Chattanooga, TN	S	NSP, NOMS, NORS
Nashville, TN	S	NSP, NOMS, NORS
Brownsville, TX	S	NOMS, NORS
Dallas, TX	S	NOMS, NORS
Fort Worth, TX	S	NSP, NOMS
Houston, TX	S	NSP, NOMS
Salt Lake City, UT	S	NSP, NOMS, NORS
Annandale, VA	S	NOMS, NORS
Richmond, VA	S	NSP, NOMS
Illwaco, WA	S	NOMS, NORS

Table A-4. Systems Sampled in More Than One Survey
(continued)

Location	Source	Surveys in which the system was sampled
Seattle, WA	S	NSP, NORS
Milwaukee, WI	S	NSP, NOMS, NORS
Huntington, WV	S	NSP, NOMS, NORS
Wheeling, WV	S	NOMS, NORS

G = Groundwater

S = Surface water

A.2.4 Testing for Biases in the Data

There was concern that the selection of sample sites in some of the surveys was biased toward VOC contamination, which, when combined with other random survey data, would bias the national projections toward a higher estimated frequency of occurrence and/or mean concentration. Purposeful selection of sites having a higher than average probability of contamination with VOCs was in fact the design of the nonrandom portion of the GWSS. It has been suggested that the NORS, NOMS, and NSP surveys also may have involved a bias towards systems known or suspected to be contaminated; however, this could not be confirmed.

Initially, consideration was given to excluding the GWSS nonrandom data for all VOCs when combining the survey data because the analysis presented by Westrick et al. (1983) showed that 21.2% of the random supplies had at least one VOC above its quantitation limit, whereas 27.3% of the nonrandom supplies showed contamination. The nonrandom portion of the GWSS was reported to have a higher frequency of occurrence of VOCs at all concentration levels for both large and small systems. At higher concentrations, there was a two to four times higher frequency of occurrence of VOCs in the nonrandom sample. It is important to note that these comparisons are based on the combined results for all VOCs. There was some concern, however, that sites selected because of suspected contamination with one or another specific VOC would not necessarily be biased for other VOCs. Westrick et al. (1983) did not present a comparison of the random and nonrandom data on a chemical-by-chemical basis, so it was not clear whether it was appropriate to exclude the GWSS nonrandom data for each VOC. It was decided, therefore, that an analysis would be performed on each VOC to evaluate whether there was a statistically significant difference in the frequency of occurrence and in the mean of the positive values observed in the random and nonrandom portions of the GWSS.

To test the difference in frequency of occurrence, the results for each VOC at each site were classified as positive or negative and summarized in a two-way table as shown below:

Portion of GWSS	Results		Total
	Positive	Negative	
Random	n_{11}	n_{12}	$n_{1.}$
Nonrandom	n_{21}	n_{22}	$n_{2.}$
Total	$n_{.1}$	$n_{.2}$	$n_{..}$

Comparisons of relative frequencies of positive results in the random and nonrandom segments of the GWSS were based on the χ^2 statistic,

$$\chi^2 = \frac{(n_{11}\, n_{22} - n_{12}\, n_{21})^2\, n_{..}}{n_{1.}\, n_{2.}\, n_{.1}\, n_{.2}}$$

with n's defined in the table above. Under the null hypothesis that the relative frequencies for the random and nonrandom segments are equal, the test statistic has an approximate chi-square distribution with 1 degree of freedom; this distribution was used to compute the P values for each VOC of interest that was examined in the GWSS.

The mean values of the positive samples in the random and nonrandom portions of the GWSS were compared using the "t" test, which tests the null hypothesis that the two means are the same (i.e., $u_1 = u_2$). The statistic for testing the equality of two population means u_1 and u_2 using independent samples from each are as follows:

$$t = (\bar{x}_1 - \bar{x}_2) \,/\sqrt{s^2\,(1/n_1 + 1/n_2)}$$

for n_1 and n_2 observations with a pooled variance (s^2) of:

$$s^2 = [(n_1 - 1)\, s_1^2 + (n_2 - 1)\, s_2^2] \,/\, (n_1 + n_2 - 2)$$

where $\bar{x}_1$ and $\bar{x}_2$ are the observed sample means of the two groups and s_1^2 and s_2^2 are the corresponding variances. An underlying assumption for use of the "t" test is that the variables are normally and independently distributed in each group. The normal distribution is not considered an acceptable model for the values of the positive samples because of the positive skewness and large coefficient of variation of their distribution. Therefore, the tests were based on natural logarithms of the concentrations to make the normality assumption more reasonable.

Table A-5 presents the results of the comparison of the frequency of the positives and of the means of the positives for each VOC in the random and nonrandom portion of the GWSS. The P_t value indicates the significance level for evaluating the null hypothesis that the means of the random and nonrandom sample are equal. This value represents the probability that the null hypothesis (i.e., the population means are equal) has been rejected on the basis of the sample means when it is actually true. For example, the results for benzene shown in Table A-5 indicate that there is a 69% probability of being in error if one were to reject the hypothesis that the population means for randomly and nonrandomly selected sites are the same based on the sample means of 4.1 ug/l for the nonrandom and 6.2 ug/l for the random sample observed. Similarly, the P_{χ^2} value represents the level of significance for evaluating the null hypothesis that the frequency of positives are the same. Again, referring to benzene, the P_{χ^2} value indicates that there is a 15% probability of being in error by rejecting the hypothesis that the frequency of occurrence of benzene in samples selected randomly and nonrandomly in the GWSS are the same based on the observed frequencies of 1.7% for the nonrandom and 0.7% for the random samples.

The critical P-value selected for this analysis was 0.01, implying the acceptance of no more than a 1% probability of being in error by rejecting the null hypothesis of equal means or equal frequencies. Using a critical value of 0.01, it can be assumed that, for those P values which are less than 0.01, the null hypothesis should be rejected (i.e., for a null hypothesis $u_1 = u_2$, the alternative hypothesis, $u_1 \neq u_2$, should be chosen). On the other hand, for values that are greater than 0.01, it cannot be directly assumed that the null hypothesis is true. It is only known that the two values are not significantly different; it is not known if they are statistically the same. However, assuming the null hypothesis is testing for equality between two values, the P values obtained from the test can be used as a general guide to determine how similar the two values are. A higher significance level (e.g., P = 0.70) would denote a greater similarity; a lower level (e.g., P = 0.05) would denote a greater difference.

In evaluating the null hypothesis based on the P value, the size of the sample on which the test of significance is made is also important. For small samples, the null hypothesis is likely to only be rejected if it is very

Table A-5. Results of Comparative Tests for Random and Nonrandom GWSS Data

Chemical	NR/R[a]	Number of positive samples[b] (n)	Percent positive[b]	Mean (x) (ug/l)	Standard deviation (s) (ug/l)	Range (ug/l)	P_t[c]	P_{χ^2}
Benzene	NR	8	1.7	4.1	4.9	0.50-12	0.69	0.15[d]
	R	3	0.7	6.2	7.7	0.61-15		
Carbon tetrachloride	NR	15	3.2	2.2	4.2	0.20-15	0.54	0.92
	R	15	3.3	1.7	4.0	0.20-16		
Chlorobenzene	NR	1	0.2	2.7	--	--	--	0.33[d]
	R	0	0	--	--	--		
o-Dichloro-benzene	NR	2	0.4	2.5	0.35	2.2-2.7	--	0.16[d]
	R	0	0	--	--	--		
m-Dichloro-benzene	NR	0	0	--	--	--	--	--
	R	0	0	--	--	--		
p-Dichloro-benzene	NR	4	0.9	0.77	0.09	0.70-0.90	0.71	0.70[d]
	R	5	1.1	0.75	0.31	0.52-1.3		
1,2-Dichloro-ethane	NR	7	1.5	3.4	2.9	1.1-9.8	0.01	0.22[d]
	R	3	0.7	0.68	0.23	0.53-0.95		
1,1-Dichloro-ethylene	NR	15	3.2	0.59	0.71	0.22-3.0	0.28	0.25
	R	9	2.0	1.4	2.0	0.22-6.3		
cis,trans-1,2-Di-chloroethylene	NR	38	8.0	8.5	21	0.21-120	0.06	0.003
	R	16	3.5	1.0	0.56	0.21-2.0		
Tetrachloro-ethylene	NR	43	9.1	4.7	11	0.22-69	0.04	0.37
	R	34	7.5	1.5	4.0	0.21-23		
1,1,1-Trichloro-ethane	NR	50	10.6	2.1	3.3	0.20-21	0.17	0.01
	R	27	5.9	1.7	3.6	0.20-18		
Trichloro-ethylene	NR	61	12.9	9.0	22	0.20-130	0.90	0.001
	R	30	6.6	8.1	17	0.24-78		
Vinyl chloride	NR	6	1.3	4.4	2.9	1.4-8.4	0.22	0.06[d]
	R	1	0.2	1.1	--	--		

[a]NR = nonrandom; R = random

[b]Based on 456 random and 473 nonrandom samples from supplies serving 25 or more people.

[c]Based on the natural logarithms of the positive concentrations (see text).

[d]Data may be unreliable due to the small number of positive samples (i.e., < 5 for random and/or nonrandom data).

wrong. Consequently, a hypothesis of equality may be accepted when it is wrong because the test for being significantly different at the 0.01 level is more stringent. In contrast, with a large sample small departures from the null hypothesis can be determined to be statistically significant, even though they are quite unimportant in practice.

As can be seen from the results shown in Table A-5, there is an apparent general trend of higher frequencies of occurrence and higher means in the nonrandom samples. However, there are few cases where the differences are statistically significant at the 0.01 level. With respect to means of positives, only 1,2-dichloroethane is found to have a statistically significant difference (actually, borderline) in the means (the nonrandom being higher, as would be expected). For the comparison of frequency of occurrence, statistically significant differences were found for only three of the VOCs: cis/trans-1,2-dichloroethylene, 1,1,1-trichloroethane, and trichloroethylene. Again, the frequencies were higher in the nonrandom samples as would be expected. (Note that the small number of positive samples for several of the VOCs makes the analysis of the frequencies of questionable validity.)

Based on these comparisons, it was decided that in preparing the national projections, the GWSS nonrandom data would be included except for the four VOCs found to have statistically significant differences in the mean of the positives or frequency of positives.

A.2.5 Establishing a Common Minimum Quantifiable Concentration for the Combined Survey Data

As noted in the discussion on computing averages for VOCs in supplies, the minimum quantifiable concentration for an analytical technique defines the level below which it cannot be determined whether the VOC is present and, if so, at what concentration. If a common minimum quantifiable concentration was used across all surveys, then the national projections would provide estimates of the number of systems at various ranges of contamination levels above the minimum quantifiable concentration. Below that concentration, only a total number of systems would be estimated for the range of 0 ug/l to the maximum possible concentration, i.e., just below the minimum quantifiable concentration. The number of systems having no contamination and the distribution of systems at various levels below the minimum quantifiable concentration could not be determined.

In many cases, different minimum quantifiable concentrations were used in the different surveys and for different analyses in the same survey. Consequently, some supplies in the combined data set were reported as having no measured VOC (i.e., negative systems) with a maximum possible concentration greater than quantified levels reported for other supplies analyzed with more sensitive methods.

In some cases, it was reasonable to use the highest "negative" value as the common minimum quantifiable concentration above which national estimates of the distribution of systems containing various VOC levels are made and below which only a total number of systems is given. Any positive values below this level were used as evidence that some supplies in this latter group are contaminated, i.e., all negative values are not necessarily 0 ug/l. These positive values were not included with positive values above the established common minimum quantifiable concentration used for selecting the appropriate model, etc. for estimating national occurrence.

In several instances, it happened that the selection of the highest negative value resulted in many, and sometimes most, of the measured positive values falling below that level, leaving too few positives above that level for completing the national projections. Three major alternatives were considered for handling high negative values in these cases. The first alternative was to establish the common minimum quantifiable concentration at some lower level that did not exceed substantial numbers of positive data points, and treat the high negative values as though they were positives at their maximum possible concentration. This would be generally consistent with the rules for averaging samples described earlier. It was observed, however, that in a large number of cases, this would result in a substantial number of the resulting total positive values being contributed from data where the VOC was not actually observed; in some cases this contribution would exceed the number of actual positive values. This was determined to be an improper use of the data.

The second alternative was to simply discard the high negative data. This was also considered inappropriate since it meant essentially eliminating valid data because it could not be made to fit the projection methodology. Furthermore, its elimination would artificially raise the computed frequency of positives by lowering the total number of systems sampled.

The third alternative, and the one selected for the national projections, was to retain the data, but treat them as though they were negative data below the lower common minimum quantifiable concentration selected for the combined survey data. While it is true that VOCs could be present in those supplies at a higher concentration, the other data suggested that the probability is greater that they are not. This alternative also avoids the elimination of valid data from the analysis. (It should be noted that, while this third alternative is used for the reported national projections, projections were also calculated using the first alternative to give the more conservative estimate; these results are noted in the text).

A.2.6 Model Selection

In developing methods for estimating the numbers of drinking water systems and people affected by different pollutant levels, it was necessary to select a statistical model for the distribution of positive concentrations for each data set. The following considerations guided the selection of a model:

- The same model should be applicable to data from different system size groups for a given pollutant (to facilitate comparisons and evaluation of estimation error).
- A continuous distributional model should be used where appropriate (to smooth out random variations in relative frequency among concentration intervals).
- The appropriateness of any continuous model should be checked through goodness-of-fit tests.
- Estimates from continuous models should provide upper bounds on the upper tail of the observed distribution (to avoid underestimating the number of systems with high-level contamination).

Three types of continuous models were investigated:

- Statistical distributions: e.g., the lognormal (Aitchison and Brown 1957) and gamma (Johnson and Kotz 1970) distributions;
- Transformations: the Johnson (1949) system of transformation to normality; and
- Empirical models: fitting the cumulative frequency with a polynomial function of concentration.

The adequacy of different distributional models was tested by three goodness-of-fit tests: Kolmogorov-Smirnov, Cramer-von Mises, and Anderson-Darling

(Stephens 1974). A model was considered unsatisfactory if it failed more than one of these tests at the 0.05 significance level. None of the three types of models worked consistently for different pollutant size-group data sets.

Of the models investigated, the delta distribution based on the lognormal distribution (Aitchison and Brown 1957) seemed the most appropriate a priori. This model has been used successfully in a wide variety of water contamination problems. It allows for the positive probability of zero (not detected) results and the skewed distribution of positive results that generally characterize the drinking water data. However, in many cases this model failed the goodness-of-fit tests for data from at least one size group. In other cases there were insufficient positive results to test whether the model was appropriate.

Based on the evaluations described above, it finally was decided that no continuous model could be identified that would be useful for the drinking water data. Therefore, a discrete model had to be employed. The model adopted was the multinomial distribution (Johnson and Kotz 1969), in which the proportion of the distribution in a specified concentration interval is estimated by the observed relative frequency for that interval. The intervals used were the ones of interest in the evaluation (<MQC*, MQC-5 ug/l, 5-10 ug/l, 10 ug/l intervals from 10 to 100 ug/l, and > 100 ug/l).

- Establishing System Size Groupings

Consideration was given to developing estimates from data grouped by system size because it was thought that contamination might be more likely in larger systems located in more populous and probably more industrialized areas. The five system size groups shown below formed the starting point for grouping data by system size:

Group	Size range (number of people served)
1 (very small)	1-500
2 (small)	501-3,300
3 (medium)	3,301-10,000
4 (large)	10,001-100,000
5 (very large)	> 100,000

*MQC is the Minimum Quantifiable Concentration set for the combined survey data (see A.2.5, above).

Frequency tables showing the number of systems sampled and the numbers of positive and negative results for each of these five size groups were produced for groundwater and surface water systems for each pollutant. It was considered desirable to consolidate these groups as much as possible (consistent with the data) because relatively few systems were sampled in some of the groups.

The extent of further consolidation possible was evaluated by comparing the relative frequencies of positives in different groups through a statistical test procedure. Group relative frequencies were compared in the following order, and the groups were combined when no significant difference in relative frequency of positives was found:

1. Groups 1 and 2.
2. Groups 4 and 5.
3. Group 3 with groups 1 and 2 combined.
4. Groups 1, 2, and 3 combined with groups 4 and 5 combined.

Step 3 was done only if groups 1 and 2 could be combined as a result of step 1; step 4 was done only if combinations in previous steps were possible. The order of the comparisons was chosen based on the possibility of a relationship (trend) between system size and the percentage of positive systems.

In performing the statistical test for equal percentages of positives in two size groups, the first step was to form a 2 x 2 summary table as illustrated below for groups 1 and 2:

Size group	Test results		Total
	Negative	Positive	
1	a	b	a + b
2	c	d	c + d
Total	a + c	b + d	n

where

a = the number of negative results for group 1.
b = the number of positive results for group 1.
a + b = the number of systems sampled in group 1.
n = a + b + c + d, the number of systems sampled in both groups, etc.

The test statistic was:

$$\chi^2 = \frac{(|ad - bc| - 1/2n)^2 n}{(a + b)(a + c)(b + d)(c + d)}$$

When this statistic exceeded the critical value 3.84 (the 95th percentile of the chi-squared distribution with 1 degree of freedom), the hypothesis of equal relative frequencies of positives in the two groups was rejected, and the groups were not combined. The chi-squared test for homogeneity of percentages in two populations is discussed by Snedecor and Cochran (1967).

In some cases, the expected number of positive systems was too small for the χ^2 test to be used (e.g., $(a + b)(b + d)/n < 5$ for group 1 under the hypothesis of equal proportions positive). In such cases, the usual alternative procedure, Fisher's Exact Test, was used to test equality of proportions positive. The application of Fisher's test is described in Ostle (1963).

- Projections of National Occurrence

After the final system size groups were selected for a pollutant, the national projections were computed. First the proportion of systems in each concentration interval of interest was estimated for each size group by the observed relative frequency for the sampled systems. The proportions of systems above the different specified concentrations also were estimated for each size group (again by the observed relative frequency for sampled systems). For example, if 100 systems were sampled in a given size group and three were found in the range 40-50 ug/l, the estimated percentage of systems in that range was 3%; if ten out of the 100 systems sampled were above 40 ug/l, the estimated percentage of systems above 40 ug/l was 10%.

The number of systems above each concentration limit for a given size group was estimated by multiplying the observed relative frequency (p_i) by the total number of systems (N_i) in that group. Then the total number of systems of all sizes above a given concentration was estimated by the sum of estimates for the k individual system size groups:

$$m = \sum_{i=1}^{k} N_i \, p_i .$$

It can be shown based on the multinomial model that m is an unbiased estimator of the total number of systems above a specified concentration (M), and that m has variance

$$\text{Var}(m) = \sum_{i=1}^{k} N_i^2 \left(\frac{N_i - n_i}{N_i - 1} \right) \frac{P_i (1-P_i)}{n_i}$$

where n_i is the number of systems sampled out of the N_i systems in group i and P_i is the true percentage of systems above the specified concentration in group i. Following Cochran (1963), the term $P_i(1-P_i)/n_i$ in Var(m) was replaced with its unbiased estimator, $p_i(1 - p_i)/(n_i - 1)$, to estimate Var(m). Then an approximate 95% confidence interval on M was calculated from

$$m \pm 1.96 \left[\hat{\text{Var}}(m)\right]^{1/2}.$$

The accuracy of this interval improves with increasing sample size (n_i) and is better when P_i values are not close to zero. When confidence limits obtained from the approximation were outside feasible M values (i.e., less than zero or greater than $N = \sum N_i$), the limits were reset to the nearest feasible value.

Projections for numbers of people exposed to concentrations above specified limits were computed in the manner described above, letting N_i represent the number of people served by systems in the ith system size group.

APPENDIX B

System Size Grouping and Selection of Model for Estimating National Occurrence of 1,1-Dichloroethylene in Drinking Water Supplies

As indicated in Appendix A (A.2.6), an initial step in the estimation process was to group the data based on system size. Based on results of statistical tests comparing percentages positive in five initial size groups, groundwater data was collapsed into two groups:

- $\leq$ 10,000 persons served
- > 10,000 persons served

(Summary statistics for initial and final groundwater groups are given in Table B-1. Results of the tests are shown in Table B-3.) For surface water, data was collapsed into two groups:

- $\leq$ 10,000 persons served
- > 10,000 persons served.

(Summary statistics and test results are given in Tables B-2 and B-3, respectively.) Only one surface water system was sampled in groups 1-3; therefore, these groups were not combined with 4 and 5 because of insufficient data to test for differences in proportions positive.

For both groundwater and surface water data, the next step was to fit a delta distribution to each system size grouping with sufficient positive data. The delta distribution has cumulative distribution function:

$$P(X \leq x) = \begin{cases} 0 & , x < 0 \\ \delta & , x = 0 \\ \delta + (1-\delta)F(x), & x > 0 \end{cases}$$

with

$$F(x) = \int_{-\infty}^{(\log_e x - \mu)/\sigma} f(z)dz,$$

where $f(z)$ is the standard normal probability density function. The mean and standard deviation of $\log_e$-transformed data were used to estimate the para-

Table B-1. Frequency of Positive Systems by Size Groups for Groundwater Systems

	System size	Number negative	Number positive	Number sampled	Percent positive
Initial groups					
(1)	1-500	228	2	230	0.87
(2)	501-3,300	199	4	203	1.97
(3)	3,301-10,000	150	4	154	2.60
(4)	10,001-100,000	298	14	312	4.49
(5)	> 100,000	38	1	39	2.56
	All	913	25	938	2.67
Final groups					
(1,2,3)	≤ 10,000	577	10	587	1.70
(4,5)	> 10,000	336	15	351	4.27
	All	913	25	938	2.67

Table B-2. Frequency of Positive Systems by Size Groups for Surface Water Systems

	System size	Number negative	Number positive	Number sampled	Percent positive
Initial groups					
(1)	1-500	--	--	0	--
(2)	501-3,300	--	--	0	--
(3)	3,301-10,000	1	0	1	0.00
(4)	10,001-100,000	19	0	19	0.00
(5)	> 100,000	81	2	83	2.41
	All	101	2	103	1.94
Final groups					
(1,2,3)	≤ 10,000	1	0	1	0.00
(4,5)	> 10,000	100	2	102	1.96
	All	101	2	103	1.94

Table B-3. Chi-Squared Tests Comparing System Size Group Proportions Positive

System size groups compared	Groundwater			Surface water		
	No. of systems	Test stat.	Decision[a]	No. of systems	Test stat.	Decision[a]
1 vs. 2	433	b	Pass	0	Not done	
4 vs. 5	351	b	Pass	102	b	
1,2 vs. 3	587	b	Pass	0	Not done	
1,2,3 vs. 4,5	938	4.65	Fail	103	Not done	

[a]Critical value for χ^2 test ($\alpha = 0.05$) is 3.84.

[b]Expected number of positives too small for χ^2 test. Used Fisher's Exact Test (Ostle 1963).

meters μ and σ; δ was estimated by the observed proportion of negative values. The goodness-of-fit of the delta distribution was tested, and the model was adopted if no more than one of the three tests failed for each size group. The results in Table B-4 show that the model failed for groundwater, and there was insufficient data to test the model for surface water. Therefore, the multinomial model was used as the basis for estimation.

Table B-4. Goodness-of-Fit Tests for Delta Distribution
1,1-Dichloroethylene

System type	System size (population served)	Parameter estimates[a] N	$\hat{\delta}$	$\hat{\mu}$	$\hat{\sigma}$	Anderson-Darling[b] Test stat.	Decision	Cramer-von Mises[c] Test stat.	Decision	Kolmogorov-Smirnov[d] Test stat.	Decision
Groundwater	≤ 10,000	587	0.983	-0.42	4.04	(Insufficient data for test)					
	> 10,000	351	0.957	-0.91	4.27	1.010	Fail	0.152	Fail	0.965	Fail
Surface water	≤ 10,000	1	1.000	--	--	(Insufficient data for test)					
	> 10,000	102	0.980	-1.14	1.74	(Insufficient data for test)					

[a] N = number of systems sampled; $\hat{\delta}$, $\hat{\mu}$, and $\hat{\sigma}$ are estimates of the delta distribution parameters.

[b] Critical value for 0.05 level of significance = 0.787.

[c] Critical value for 0.05 level of significance = 0.126.

[d] Critical value for 0.05 level of significance = 0.895.

APPENDIX C

Calculation of Population-Concentration Values

Chapter 5 presents population-concentration values for intake from air and drinking water. The population-concentration is calculated as the sum of the population exposed (P) times concentration (C) at various concentration levels, or

$$\text{population-concentration} = \sum_{i=1}^{n} C_i \times P_i.$$

For example, if 10,000 persons were exposed to a chemical in drinking water at 5 ug/l and 4,000 additional persons were exposed to the same chemical at 10 ug/l, the population-concentration calculated would be:

$$\text{population-concentration} = (10{,}000 \text{ persons} \times 5 \text{ ug/l}) + (4{,}000 \text{ persons} \times 10 \text{ ug/l}) =$$

$$90{,}000 \text{ ug/l} \times \text{persons}.$$

These calculations would be straightforward if the number of individuals exposed to specific concentrations of the chemical were known. However, it is not possible to determine the specific concentration to which each individual or subpopulation is exposed. Instead, the calculations are based on the estimate of the number of individuals exposed to concentrations within various intervals (e.g., >5-10 ug/l). An example of a typical set of estimates of the population exposed to a chemical in groundwater and surface water systems is presented in Table C-1.

Table C-1. Total Estimated Population (in Thousands) Exposed to a Chemical in Drinking Water at the Indicated Concentration Ranges

System type	Total served in U.S. (thousands)	Population (thousands) exposed to concentrations (ug/l) of:			
		< 0.2	0.2-5	>5-10	>10
Groundwater	69,000	67,000	1,700	73	0.0
Surface water	130,000	130,000		0.0	0.0
TOTAL	200,000	200,000		73	0.0
(% of total)	(100%)	(100%)		(0.04%)	(0.0%)

The groundwater and surface water data in Table C-1 represent the two types of projections of the populations exposed to concentrations of a chemical within certain intervals that could be made from the available data. In the first case, represented by groundwater in Table C-1, it was possible to estimate the size of the population exposed within several discrete concentration ranges. In the second case, represented by surface water in Table C-1, it was only possible to estimate an overall concentration range within which the entire population is expected to be exposed. As described below, the approach to the calculation of the population-concentration values differed for these two cases.

C.1 CALCULATION OF POPULATION-CONCENTRATION ESTIMATES WHERE DATA ARE AVAILABLE FOR SEVERAL DISCRETE INTERVALS

For this situation, a best case, mean best case, mean worst case, and worst case estimate were calculated. The best-case is calculated by using the lower concentration bound for each interval to multiply by the population exposed within that interval. Using the groundwater data in Table C-1, the best case is calculated as:

$$\begin{gathered}\text{population-concentration (best case)} = (67{,}000{,}000 \text{ persons} \times 0 \text{ ug/l}) + \\ (1{,}700{,}000 \text{ persons} \times 0.2 \text{ ug/l}) + (73{,}000 \text{ persons} \times 5.01 \text{ ug/l}) = \\ 710{,}000 \text{ ug/l} \times \text{persons}\end{gathered}$$

For the worst case, the upper limit in each concentration interval is used.

$$\begin{gathered}\text{population-concentration (worst case)} = (67{,}000{,}000 \text{ persons} \times 0.19 \text{ ug/l}) + \\ (1{,}700{,}000 \text{ persons} \times 5 \text{ ug/l}) + (73{,}000 \text{ persons} \times 10 \text{ ug/l}) = \\ 22{,}000{,}000 \text{ ug/l} \times \text{persons}\end{gathered}$$

These values give the absolute lowest and absolute highest values which can be obtained using the data presented.

Two intermediate values are also calculated -- the mean best case and the mean worst case. These values are calculated by using the mean value within each concentration interval (i.e., the midpoint of that interval) except for the lowest interval. For the mean best case, 0 ug/l is used for the lowest interval; for the mean worst case the upper bound of the lowest interval is

used. The lower (i.e., 0 ug/l) and upper bounds of the lowest concentration interval are used rather than the midpoint value because of the considerable uncertainty in the distribution of concentrations in the lowest interval given that most of the sample data for that interval are reported as "undetected." Examples of these calculations based on the groundwater data in Table C-1 follow:

$$\text{population-concentration (mean best case)} = (67{,}000{,}000 \text{ persons} \times 0 \text{ ug/l}) + (1{,}700{,}000 \text{ persons} \times 2.6 \text{ ug/l}) + (73{,}000 \text{ persons} \times 7.5 \text{ ug/l}) = 5{,}000{,}000 \text{ ug/l} \times \text{persons}$$

$$\text{population-concentration (mean worst case)} = (67{,}000{,}000 \text{ persons} \times 0.19 \text{ ug/l}) + (1{,}700{,}000 \text{ persons} \times 2.6 \text{ ug/l}) + (73{,}000 \text{ persons} \times 7.5 \text{ ug/l}) = 18{,}000{,}000 \text{ ug/l} \times \text{persons}$$

In some instances, it was projected that a portion of the population was exposed to concentrations greater than 100 ug/l, with no estimate of the upper bound to the concentration interval. In those cases, the concentration intervals used were chosen to fit the actual sampling data. For example, if the data above 100 ug/l for a chemical were 130 and 160 ug/l, the concentration interval assigned would be > 120-160 ug/l.

C.2 CALCULATION OF POPULATION-CONCENTRATION WHERE DATA ARE AVAILABLE ONLY FOR AN OVERALL CONCENTRATION RANGE OF EXPOSURE

In cases where only an overall range applicable to the entire population could be determined, best case, median case, and worst case population-concentration estimates were calculated as follows. The best case was always equal to 0 ug/l x persons (total population using systems x 0 ug/l), while the worst case was calculated as the total population using the systems times the upper limit of the concentration range (130,000,000 persons x 5 ug/l = 650,000,000 ug/l x persons for in the surface water data in Table C-1). For the median case, the median of the positive values reported for that chemical in the water supplies sampled was used, and was multiplied by the total population. For the surface water data in Table C-1, the median positive value was 0.36 ug/l, giving a population-concentration estimate of 130,000,000 persons x 0.36 ug/l, or 47,000,000 ug/l x persons.

C.3 CALCULATION OF TOTAL POPULATION-CONCENTRATION ESTIMATES

Once the population-concentration estimates were calculated for each chemical for both groundwater and surface water systems, these values were added to obtain total population-concentration estimates for each chemical. In cases where data were available on discrete intervals for one water source and for an overall interval for the other source, it was necessary to add separately the mean best case and mean worst case estimates for the former to median case estimates for the latter. This procedure was necessary to obtain mid-range estimates of population-concentration for the chemicals.