

**Occurrence Assessment for Disinfectants and
Disinfection By-Products (Phase 6a)
in Public Drinking Water**

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Occurrence Assessment for Disinfectants and Disinfection By-Products (Phase 6a) in Public Drinking Water

1. Introduction

The EPA Office of Ground Water and Drinking Water (OGWDW) is currently developing national primary drinking water regulations for disinfectant and disinfection by-product contaminants. Thirteen contaminants are being considered to be regulated under Phase 6. These contaminants, referred to as Phase 6a, are the subject of this report.

Occurrence assessments support several aspects of the drinking water regulatory development process. Information on the distribution of contaminant occurrence levels in public water supplies of various source and size characteristics assists OGWDW in estimating the number of systems and the size of the affected populations currently experiencing contaminant levels exceeding the Maximum Contaminant Level (MCL) alternatives under consideration. This information is critical for conducting the cost impact analyses of the regulatory alternatives. The information on contaminant occurrence levels also supports the identification of the Best Available Technology (BAT) necessary for setting the MCL and for granting variances. In addition, the occurrence estimates are used to develop exposure assessments and, subsequently, the contribution of drinking water, relative to other sources of exposure, to total intake. This information is important for setting the Maximum Contaminant Level Goal (MCLG) for a contaminant. The exposure information also is used to estimate the "baseline" health impact assessment of current levels and for evaluation of the health benefits of the regulatory alternatives.

2. Summary of Data Sources

Exhibit 2.1 summarizes the occurrence data for the disinfectants and disinfection by-products in the current regulatory effort. Following is a description of the major surveys and studies including information relevant to the occurrence data.

National Organics Reconnaissance Survey

The USEPA conducted the National Organic Reconnaissance Survey (NORS) in early 1975 in order to examine the occurrence of organic chemicals in drinking waters. The NORS primary objective was to characterize the extent and presence of chloroform, bromodichloromethane, dibromochloromethane, and bromoform. Secondary objectives of the study included the determination of the effects of raw water source and treatment practices on the formation of these compounds. Eighty water supplies, representing a wide variety of raw water sources and treatment technologies, were chosen for the study. The water supplies were geographically distributed so as to obtain national occurrence information. Of the 80 water supplies, 16 had ground water sources and 64 had surface water sources. A reducing agent was not added at the time of sample collection; thus, the THM concentrations represent maximum values due to the consumption of the residual chlorine.

National Organics Monitoring Survey

The National Organics Monitoring Survey (NOMS) was conducted by the EPA from March 1976 to January 1977 to identify sources and frequency of occurrence of organics and inorganics in drinking water supplies. In addition, the survey was intended to provide a data base in support of establishing maximum contaminant levels (MCL) for the contaminants in the nation's drinking water supplies. NOMS was conducted in three phases: Phase I - March to April 1976; Phase II - May to July 1976; and Phase III - November 1976 to January 1977. In NOMS, finished water from 113 public water supplies were sampled. Of the 113 supplies, 18 had ground water sources, 91 had surface water sources, and four had mixed ground water and surface water sources. Finished water from the treatment plants were sampled for chloroform, bromoform, bromodichloromethane, and dibromochloromethane.

Rural Water Survey

The Rural Water Survey (RWS) was conducted by the EPA between 1977 and 1980 to evaluate the status of drinking water in rural America as required by Section 3 of the Safe Drinking Water Act. More than 2,000 households served by 648 public water supplies (494 ground water, 154 surface water) were surveyed. Of the 2655 samples obtained, 800 were analyzed for purgeable halocarbons, including the four trihalomethanes. It should be noted that some samples were analyzed up to 27 months after collection. Also, a reducing agent was not added at the time of sample collection; thus, the THM concentrations represent maximum values due to the consumption of the residual chlorine.

Community Water Supply Survey

The Community Water Supply Survey (CWSS) was conducted in 1978 by the EPA to determine the occurrence of organic and inorganic compounds in public water supplies. Drinking water samples were provided by 452 systems, including 388 utilities serving populations less than 10,000. The survey included analyses for chloroform, bromoform, bromodichloromethane, and dibromochloromethane. Finished water samples and distribution system samples were averaged for each system due to inconsistencies in reporting. It should be noted that the samples were one to two years old prior to analysis for the THMs. Also, a reducing agent was not added at the time of sample collection; thus, the THM concentrations represent maximum values due to the consumption of the residual chlorine.

Ground Water Supply Survey

The Ground Water Supply Survey (GWSS) was conducted from December 1980 to December 1981 by the EPA to develop data on the occurrence of volatile organic chemicals (VOC) in ground water supplies. Out of a total of 945 ground water systems, 466 systems were chosen at random, while the remaining 479 systems were chosen on the basis of location near industrial, commercial, and waste disposal activities. 618 systems served populations < 10,000 people. The samples were collected at or near the entrance to the distribution system. Analyses for chloroform, bromodichloromethane, dibromochloromethane, and bromoform were performed on samples that were dechlorinated at the time of collection. It is likely that many of the small systems were not disinfecting with chlorine when this survey was conducted.

AWWARF National Trihalomethanes Survey

In 1987 the American Water Works Association Research Foundation (AWWARF) partially funded a grant awarded to the Metropolitan Water District of Southern California (MWD) to perform a national survey of THMs. The survey was conducted to determine the extent and costs of compliance with the THM maximum contaminant level (MCL). Questionnaires were completed by 910 utilities, each serving more than 10,000 customers. Participants provided quarterly total THM concentrations (mean, maximum, and minimum) from 1984 through 1986. Data on each utility's source of water, chemicals used, populations served, etc. were obtained. Information on any treatment modifications that were made to achieve compliance, along with the costs and any water quality problems associated with the changes, was collected from each utility (Meadow, 1987 and McGuire and Meadow, 1988).

EPA/AMWA/CDHS Study

In 1987, EPA funded a cooperative agreement with the Association of Metropolitan Water Agencies (AMWA) to study the formation and control of disinfection by-products (DBPs) in drinking water systems. Utilities using a variety of source water qualities, water treatment processes, and disinfection schemes were included in the study. Twenty-five utilities nationwide participated in the study performed by the Metropolitan Water District of Southern California (MWD) and James M. Montgomery Consulting Engineers, Inc. The California Department of

Health Services (CDHS) also contracted with MWD to include 10 California utilities in the baseline phase of the study. Samples of plant influent and clearwell effluent were collected from each utility on a quarterly basis for 1 year. The effluent samples were analyzed for chlorine residuals, surrogate parameters, and several chlorination DBPs including THMs, CH, DCAA, and TCAA. All samples were collected with the appropriate dechlorinating agents. During the second phase of the project, treatment modification studies were conducted at six utilities in order to identify, in a preliminary manner, the impact of treatment processes on DBP formation (Krasner et al., 1989; USEPA and AWWA, 1989).

Water Industry Data Base

The Water Industry Data Base (WIDB) was initiated through a joint effort by the American Water Works Association (AWWA) and the American Water Works Research Foundation (AWWARF). The purpose of this data base is to support the regulatory and legislative efforts of AWWA, assist AWWA in focusing research activities, and support educational endeavors of AWWA and interested parties. The study, conducted between 1989 and 1990, surveyed approximately 600 drinking water systems serving over 50,000 people in the United States. The response rate was better than 80 percent, resulting in information from approximately 500 systems in the data base. The survey covered a wide spectrum of information, including utility characteristics and finances, surface and ground water treatments, water quality monitoring, and water distribution characteristics. Data on the free chlorine residuals used by the utilities was also obtained.

AWWA 1991 Disinfection Survey

The American Water Works (AWWA) 1991 Disinfection Survey was conducted by the Disinfection Committee of AWWA's Water Quality Division. This survey is a follow-up survey to the 1978 Disinfection Survey. The purpose of this survey was to document current water industry practices regarding disinfection and water quality control. A total of 283 utilities participated in this study, responding to questions involving disinfection and quality control, including: control methodology, chlorine demand, filtration, chlorine dose, contact times, and total trihalomethane levels. In the 1991 Disinfection Survey, information was provided concerning free chlorine residual in drinking water and the number of utilities using chlorine, chloramines, and chlorine dioxide were estimated.

EPA Disinfection By-Product Field Studies

The Technical Support Division (TSD) of the Office of Ground Water and Drinking Water has conducted several Disinfection By-Product Field Studies. A study of chlorination by-products was performed from October 1987 to March 1989. Samples of source water, plant effluent, and water from a far point in the distribution system were collected from 21 community water supplies (CWS). All the systems used free chlorine at some point in the treatment process and 19 used free chlorine as the residual disinfectant. Some of the utilities used preoxidants (5 ozone; 2 chlorine dioxide) in addition to chlorine. Sixteen systems were treating surface water; 14 served populations <10,000. Concentrations of several DBPs were examined including the

four THMs, chloral hydrate (CH), dichloroacetic acid (DCAA), and trichloroacetic acid (TCAA). Residual chlorine measurements were also obtained. The samples were collected with dechlorination agents, except at the first 3 utilities where the samples were analyzed within 24 hours of sample collection.

A second study from August 1989 to November 1989 was designed to examine the use of total organic halide (TOX) as a surrogate for chlorination DBPs. Utilities were selected to obtain samples containing median total THM concentrations in the range of 50-100 $\mu\text{g/L}$. All utilities used free chlorine at some point in the treatment process and the majority used free chlorine as the residual disinfectant. Thirty of the 31 CWS treated surface water or a combination of surface and groundwater. Two systems serving populations <10,000 were sampled. Samples of plant effluent and water from one point in the distribution system were analyzed for DBPs, chlorine residuals, and surrogate parameters. All samples were collected with the appropriate dechlorinating agents.

Samples of untreated source water and treatment plant effluent were collected from 20 sites in August and September of 1991, in order to study the occurrence of chlorate. The samples were also analyzed for chlorite and bromate, and in a few cases, the organic DBPs. Four CWS used chlorine dioxide in the treatment process; 14 sites used hypochlorite solutions for chlorination; the remaining 2 CWS used gaseous chlorine. Two systems served populations <10,000.

As part of an ongoing effort, samples of source water and plant effluent are collected at utilities participating in EPA's Comprehensive Performance Evaluation (CPE) Program. The systems all use chlorine and treat surface water. Nine of the 11 systems sampled between March 1991 and February 1992 served populations <10,000. The samples are analyzed for both organic and inorganic DBPs, surrogate parameters, and chlorine residuals. All samples are dechlorinated/preserved.

EPA's Unregulated Contaminant Database

Currently, the Technical Support Division of the Office of Ground Water and Drinking Water maintains a database of unregulated contaminants in public drinking water supplies. As of December 1991, nineteen states had reported data on the individual THMs. The data are a compilation of studies with multiple analytical methods and detection limits resulting in over 14,000 samples.

Exhibit 2.1: Disinfectants and Disinfection By-Products Drinking Water Summary Table

Survey (Year) ¹	Location	Sample Information (No. of Samples)	Concentration (µg/L)			
			Range	Mean	Median	Other
Chlorine						
NORS (1975) Symons et al., 1975	80 Cities Nationwide	Finished Water at Treatment Plant	0-2.8 mg/L		0.6 mg/L ⁹	
TSD, 1992 (1987-1991)	Disinfection By-Products Field Studies	Finished Water: At the Plant (71) Distrib. System (45)	0.1-5.0 mg/L 0.0-3.2 mg/L	1.7 mg/L 0.7 mg/L	1.4 mg/L 0.5 mg/L	
AWWARF (1987) McGuire & Meadow, 1988		Finished Water From: Lakes Flowing Streams Groundwaters Mixed-supplies			2.2 mg/L ⁸ 2.3 mg/L ⁸ 1.2 mg/L ⁸ 1.0 mg/L ⁸	
EPA/AMWA/CDHS (1988-1989) Krasner et al., 1989	35 Water Utilities Nationwide	Samples from Clearwell Effluent, 4 Quarters (17)	0.3-5.2 mg/L	1.5 mg/L	1.0 mg/L	
WIDB (1989-1990)	228 SW Plants	Residual Chlorine Provided to the Average Customer	0-3.5 mg/L	0.937 mg/L	0.80 mg/L	
	215 GW Plants		0-5 mg/L	0.872 mg/L	0.325 mg/L	
AWWA Disinfection Survey (1991)	283 Utilities in the U.S.	Finished Water Entering Distribution System		0.07-5.0 mg/L	1.10 mg/L	

Disinfectants and Disinfection By-Products Drinking Water Summary Table (continued)

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Survey (Year)	Location	Sample Information (No. of Samples)	Concentration (µg/L)			
			Range	Mean	Median	Other
Chlorine Dioxide, Chlorate, and Chlorite						
AWWARF (1987) McGuire & Meadow, 1988		Finished Water From: Lakes Flowing Streams		1.0 mg/L ^a 0.6 mg/L ^a		
TSD, 1992 (1987-1991)	Disinfection By-Products Field Studies	Plants Using ClO ₂ : Chlorite at the Plant (4)	15-740	240	110	Positive Detects. 100%
		Chlorate at the Plant (4)	21-330	200	220	100%
		Plants Not Using ClO ₂ : Chlorate at the Plant (30)	<10-660	87	16	60%
		Chlorate, Dist. Syst. (4)	<10-47	18	13	75%
Chloramine						
AWWARF (1987) McGuire & Meadow, 1988		Finished Water From: Lakes Flowing Streams				Typical dosages: 1.5 mg/L 2.7 mg/L
EPA/AMWA/CDHS (1988-1989) Krasner et al., 1989	35 Water Utilities Nationwide	Samples from Clearwell Effluent, 4 Quarters (13)	0.9-5.5	2.3	1.8	
TSD, 1992 (1987-1991)	Disinfection By-Products Field Studies	At the Plant (11) Distribution System (8)	1.2-3.6 0.1-3.3	2.1 1.4	1.5 1.1	
Bromate						
McGuire et al., 1990	MWD Pilot Plant Studies	Ozonation: Hydrogen Peroxide/Ozone:	Max. 60 Max. 90			
TSD, 1992 (1987-1991)	Disinfection By-Products Field Studies	Finished Water, Plants Not Using Ozone (33)	<10			DL= 5

Disinfectants and Disinfection By-Products Drinking Water Summary Table (continued)

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Survey (Year)	Location	Sample Information (No. of Samples)	Concentration (µg/L)			
			Range	Mean	Median	Other
Chloroform						
NORS (1975) Symons et al., 1975	80 Cities Nationwide	Finished Water at Treatment Plants	Max. 311		23	
NOMS (1976-1977) Bull and Kopfler, 1990	113 Community Water Supplies	Finished Water at Treatment Plants ⁴	Max. 540		22-54.5 ²	Pos. Detections: 92% - 100% ³
CWSS (1978) Brass et al., 1981	450 Water Supply Systems	Finished Water (1,100): Surface Water Ground Water		60 <0.5		Pos. Detections: 97% ³ 34% ³
RWS (1978-1980) Brass, 1981	>600 Rural Systems (>2,000 Households)	Drinking Water from: Surface Water Ground Water		84 ³ 8.9 ³	57 <0.5	Pos. Detections: 82% ³ 17% ³
GWSS (1980-1981) Westrick et al. 1983	945 GW Systems: (466 Random) (479 Nonrandom)	Serving >10,000 (307) Serving <10,000 (618)	Max. 300 Max. 430		0.5 0	90th percentile: 17 7.8
TSD, 1991 (1984-1991)	Unregulated Contam. Database - Treatment Facilities from 19 States	Sampled at the Plant (5,806)		17	5	
TSD, 1992 (1987-1991)	Disinfection By-Products Field Studies	Finished Water: At the Plant (73) Distribution System (56)	<0.2-240 <0.2-340	36 57	28 42	Positive Detects: 96 98
EPA/AMWA/CDHS (1988-1989) Krasner et al., 1989	35 Water Utilities Nationwide	Samples from Clearwell Effluent for 4 Quarters	Max. 130		9.6-15 ⁶ 14	75% of Data was Below 33

Disinfectants and Disinfection By-Products Drinking Water Summary Table (continued)

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Survey (Year)	Location	Sample Information (No. of Samples)	Concentration (µg/L)			
			Range	Mean	Median	Other
Bromodichloromethane						
NORS (1975) Symons et al., 1975	80 Cities Nationwide	Finished Water at Treatment Plants	Max. 116		8	Pos. Detections: 98% ³
NOMS (1976-1977) Bull and Kopfler, 1990	113 Community Water Supplies	Finished Water at Treatment Plants ⁴	Max. 183		5.9-14 ²	Pos.Detections: 90% ³
CWSS (1978) Brass et al., 1981	450 Systems	Finished Water (1,100): Surface Water Ground Water		12 ³ 5.8 ³	6.8 <0.5	Pos. Detections: 94% ³ 33% ³
RWS (1978-1980) Brass, 1981	>600 Rural Systems (>2,000 households)	Drinking Water from: Surface Water Ground Water		17 ³ 7.7 ³	11 <0.5	Pos. Detections: 76% ³ 13% ³
GWSS (1980-1981) Westrick et al. 1983	945 GW Systems: (466 Random) (479 Nonrandom)	Serving >10,000 (327) Serving <10,000 (618)	Max. 110 Max. 79		0.4 0	90th percentile 9.2 6.1
TSD, 1991 (1984-1991)	Unregulated Contam. Database - Treatment Facilities from 19 States	Finished Water at Treatment Plants (4,439)		5.6	3	
TSD, 1992 (1987-1989)	Disinfection By-Products Field Studies	Finished Water: At the Plant (73) Distribution System (56)	<0.2-90 <0.2-100	13 17	11 15	Positive Detects: 96% 98%
EPA/AMWA/CDHS (1988-1989) Krasner et al., 1989	35 Water Utilities Nationwide	Samples from Clearwell Effluent for 4 Quarters	Max. 82	4.1-10 ⁶	6.6	75% of Data was Below 14 µg/L

Disinfectants and Disinfection By-Products Drinking Water Summary Table (continued)

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Survey (Year)	Location	Sample Information (No. of Samples)	Concentration (µg/L)			
			Range	Mean	Median	Other
Dibromochloromethane						
NORS (1975) Symons et al., 1975	80 Cities Nationwide	Finished Water at Treatment Plants	Max. 100		2	Pos. Detections: 90% ³
NOMS (1976-1977) Bull and Kopfler, 1990	113 Community Water Supply Systems	Finished Water at Treatment Plants ⁴	Max. 280		ND-3	Pos. Detections: 78% ³
CWSS (1978) Brass et al., 1981	450 Systems	Finished Water (1,100): Surface Water Ground Water		5.0 ⁵ 6.6 ⁵	1.5 ≤0.5	Pos. Detections: 67% ³ 34% ³
RWS (1978-1980) Brass, 1981	>600 Rural Systems (>2,000 households)	Drinking Water from: Surface Water Ground Water		8.5 ⁵ 9.9 ⁵	0.8 ≤0.5	Positive Detections: 56% ³ 13% ³
GWSS (1980-1981) Westrick et al. 1983	945 GW Systems: (466 Random) (479 Nonrandom)	Serving >10,000 (327) Serving <10,000 (618)	Max. 59 Max. 63		0.7 0	90th Percentile: 9.2 5.6
TSD, 1991 (1984-1991)	Unregulated Contam. Database - Treatment Facilities from 19 States	Sampled at the Plant (4,439)		3.0	1.7	
TSD, 1992 (1987-1989)	Disinfection By-Products Field Studies	Finished Water: At the Plant (73) In Dist. System (56)	≤0.2-41 ≤0.2-41	4.9 6.6	2.0 3.4	Positive Detects: 92% 93%
EPA/AMWA/CDHS (1988-1989) Krasner et al., 1989	35 Water Utilities Nationwide	Samples from Clearwell Effluent for 4 Quarters	Max. 63		3.6 2.6-4.5 ⁶	75% of Data was Below 9.1 µg/L

Disinfectants and Disinfection By-Products Drinking Water Summary Table (continued)

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Survey (Year)	Location	Sample Information (No. of Samples)	Concentration (µg/L)			
			Range	Mean	Median	Other
Bromoform						
NORS (1975) Symons et al., 1975	80 Cities Nationwide	Finished Water at Treatment Plants	<0.5-92		<0.5	DL = 0.5
NOMS (1976-1977) Bull and Kopfler, 1990	113 Community Water Supply Systems	Finished Water at Treatment Plants ⁴	<0.3-280		ND-0.3	DL = 0.3
CWSS (1978) Brass et al., 1981	450 Systems	Finished Water (1,100) from: Surface Water Ground Water		2.1 ⁵ 11 ⁵	<1.0 <0.5	Pos. Detections: 13% ³ 26% ³
RWS (1978-1980) Brass, 1981	>600 Rural Systems (>2,000 Households)	Drinking Water from: Surface Water Ground Water		8.7 ⁵ 12 ⁵	<0.5 <0.5	Pos. Detections: 18% ³ 12% ³
GWSS (1980-1981) Westrick et al. 1983	945 GW Systems: (466 Random) (479 Nonrandom)	Serving >10,000 (327) Serving <10,000 (618)	Max. 68 Max. 110		0 0	90th Percentile: 8.3 4.1
TSD, 1991 (1984-1991)	Unregulated Contam. Database - Treatment Facilities from 19 States	Sampled at the Plants (1,409)		2.5	1	
TSD, 1992 (1987-1989)	Disinfection By-Products Field Studies	Finished Water: At the Plant (73) In Dist. System (56)	<0.2-6.7 <0.2-10	0.7 1.0	<0.2 <0.2	Positive Detects: 45% 48%
EPA/AMWA/CDHS (1988-1989) Krasner et al., 1989	35 Water Utilities Nationwide	Samples from Clearwell Effluent for 4 Quarters	Max. 72		0.33-0.88 ⁶ 0.57	75% of Data was Below 2.8

Disinfectants and Disinfection By-Products Drinking Water Summary Table (continued)

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Survey (Year)	Location	Sample Information (No. of Samples)	Concentration (µg/L)			
			Range	Mean	Median	Other
Chloral Hydrate						
TSD, 1992 (1987-1989)	Disinfection By-Products Field Studies	Finished Water: At the Plant (67) Dist. System (53)	<0.2-25 <0.2-30	5.0 7.8	2.5 4.4	Positive Detects: 90% 91%
EPA/AMWA/CDHS (1988-1989) Krasner et al., 1989	35 Water Utilities Nationwide	Samples from Clearwell Effluent for 4 Quarters	Max. 22		1.7-3.0 ⁶ 2.1	75% of Data was Below 4.1 ⁷
Dichloroacetic Acid						
TSD, 1992 (1987-1989)	Disinfection By-Products Field Studies	Finished Water: At the Plant (72) In the Dist. System (56)	<0.4-61 <0.4-75	18 21	16 17	Positive Detects: 93% 96%
EPA/AMWA/CDHS (1988-1989) Krasner et al., 1989	35 Water Utilities Nationwide	Samples from Clearwell Effluent for 4 Quarters	<0.6-46		5.0-7.3 ⁶ 6.4	75% of Data was Below 12 DL = 0.6
Trichloroacetic Acid						
TSD, 1992 (1987-1989)	Disinfection By-Products Field Studies	Finished Water: At the Plant (72) Dist. System (56)	<0.4-54 <0.4-77	13 15	11 15	Positive Detects: 90% 91%
EPA/AMWA/CDHS (1988-1989) Krasner et al., 1989	35 Water Utilities Nationwide	Samples from Clearwell Effluent for 4 Quarters			4.0-5.8 ⁶ 5.5	75% of Data was Below 15.3 DL = 0.6

Disinfectants and Disinfection By-Products Drinking Water Summary Table (continued)

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Survey (Year)	Location	Sample Information (No. of Samples)	Concentration (µg/L)			
			Range	Mean	Median	Other
Total Trihalomethanes						
AWWARF (1987) McGuire & Meadow, 1988	727 Cities Nationwide that serve >10,000 people (Quarterly mean of finished water)	10,000-25,000		60		
		Rivers		64		
		Lakes		21		
		Ground		61		
		Purchased		37		
		Mixed				
		25,000-50,000				
		Rivers		56		
		Lakes		59		
		Ground		20		
		Purchased		44		
		Mixed		42		
		>50,000				
		Rivers		49		
		Lakes		44		
		Ground		22		
		Purchased		49		
		Mixed		47		
			Overall	ND-360	42	39
		677 Cities Nationwide that serve <10,000 people	Finished Water (2,594)	ND-313	36	18
NORS (1975) Symons et al., 1975	80 Cities Nationwide	Finished Water at Treatment Plant	ND-482	68	41	90th Percentile: 120
NOMS (1976-1977) McGuire & Meadow, 1988	105 Community Water Supplies	Finished Water at Treatment Plant ⁴	ND-784	84	55	90th Percentile: 160

Disinfectants and Disinfection By-Products Drinking Water Summary Table (continued)

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Survey (Year)	Location	Sample Information (No. of Samples)	Concentration (µg/L)			
			Range	Mean	Median	Other
Total Haloaceticacids						
TSD, 1992 (1987-1989)	Disinfection By-Products Field studies	Finished Water: At the Plant (73) Dist. System (56)	<1-86 <1-136	33 38	28 35	

- ¹ Dates indicate period of sample collection
- ² Median concentrations of the three phases
- ³ Of systems sampled
- ⁴ Sampled over 3 Phases
- ⁵ Mean of the Positives
- ⁶ Range of medians for individual quarters
- ⁷ Detection limit was 0.02 $\mu\text{g/L}$ in the first quarter and 0.1 $\mu\text{g/L}$, thereafter
- ⁸ Typical dosage used by treatment plants
- ⁹ Approximate value
- ¹⁰ Includes DBAA, DCAA, MBAA, MCAA, and TCAA

Abbreviations:

AMWA	Association of Metropolitan Water Agencies
AWWA	American Water Works Association
AWWARF	American Water Works Association Research Foundation
CDHS	California Department of Health Services
CWSS	Community Water Supply Survey
DL	Detection limit
GWSS	Ground Water Supply Survey
JMM	James M. Montgomery Engineers, Inc.
MWD	Metropolitan Water District of California
ND	Not detected
NOMS	National Organics Monitoring Survey
NORS	National Organics Reconnaissance Survey
RWS	Rural Water Survey
TSD	Technical Services Division
WIDB	Water Industry Data Base

3. Disinfectants

3.1 Chlorine, Hypochlorite Ion, and Hypochlorous Acid

Chlorine hydrolyses in water to form hypochlorite and hypochlorous acid. Chlorine and hypochlorites are used to disinfect drinking water, sewage and wastewater, and swimming pools. They have also been used for general sanitation and control of bacterial odors in the food industry. In addition, chlorine is used to manufacture chlorinated lime (a fabric bleach), detinning and dezincing iron, production of synthetic rubber and plastics, and as a reagent in synthetic chemistry. Although chlorine is a highly reactive species, its fate and transport in the environment and distribution in natural waters is not well delineated. Much of the available information comes from the addition and oxidation reactions with inorganic and organic compounds known to occur in aqueous solutions. Factors such as reactant concentrations, pH, temperature, salinity, and sunlight influence these reactions (Stevens and Symons, 1977; Merck Index, 1989; Johnson and Jensen, 1986; White, 1986).

In the disinfection treatment of drinking water, chlorine is added to water as chlorine gas (Cl_2) or as calcium or sodium hypochlorite. In water, the chlorine gas hydrolyzes to hypochlorous acid and hypochlorite ion and is measured as free chlorine residual. Maintenance of a free chlorine residual throughout the distribution system is important as an indicator for external contamination indicated by an absence of a residual and for continual bacteria kill. Currently, maximum chlorine dosage is limited by taste and odor constraints and, indirectly, by regulations on total trihalomethanes (TTHM). Additionally, the implementation of the surface water treatment rule (SWTR) will increase the number of systems using chlorination and the degree of chlorine dosage due to contact time requirements.

The Water Industry Data Base (WIDB) contains results from a survey of approximately 600 drinking water systems serving over 50,000 people in the United States, conducted between 1989 and 1990. Based on data from the Water Industry Data Base (WIDB), it has been estimated that approximately 51% of surface and 77% of ground water systems, serving more than 10,000 people, currently use chlorine for disinfection in the United States. For those serving 25 to 10,000 people, 100% of the systems using surface water and 50% of the community systems using ground water use chlorine. Fifteen percent of the noncommunity systems using ground water use chlorine. It is estimated that the population exposed to chlorine from the use of chlorination alone in community drinking water is 70.3 million from surface water plants and 36 million from ground water plants serving more than 10,000 people, and 17.4 million and 16.1 million from surface and ground water plants serving between 25 and 10,000 people (WIDB, 1990).

Drinking Water

National Studies

The EPA's 1975 National Organic Reconnaissance Survey (NORS), sampled drinking water of 80 U.S. water supplies. Of these 80 supplies, 16 had ground water sources and 64 had surface water sources. Based on the survey's results, chlorine residual reportedly ranged from 0-2.8 mg/L, with an approximate median concentration of 0.6 mg/L (Symons et al., 1975).

In 1987, the American Water Works Association Research Foundation (AWWARF) sponsored a national survey of trihalomethanes (THMs) conducted by the Metropolitan Water District of Southern California. As part of this survey, alternate treatment technologies were investigated which would achieve lower THM levels. Based on survey results, typical chlorine dosage used in drinking water was found to be 2.2 mg/L, 2.3 mg/L, 1.2 mg/L, and 1.0 mg/L for systems using lakes, flowing streams, groundwaters, and mixed-supplies as their raw water sources. Overall, doses ranged from 0.1->20 mg/L (McGuire and Meadow, 1988).

The EPA's Technical Support Division (TSD) has compiled a database of its disinfection by-products field studies. The studies included a chlorination by-products survey, conducted from October 1987 to March 1989. In this survey, free chlorine was sampled in finished water at the treatment plant and in the distribution system. Out of 71 finished water samples, concentrations ranged from 0.1 to 5.0 mg/L, with a mean of 1.7 mg/L and a median of 1.4 µg/L. In the distribution system, concentrations from 45 samples ranged from 0-3.2 mg/L, with a mean and median of 0.7 mg/L and 0.5 mg/L, respectively (TSD, 1992).

Based on WIDB data from 228 surface water plants and 215 ground-water plants, chlorine residual in drinking water to the average customer was determined. From surface water plants, chlorine residual ranged from 0 to 3.5 mg/L, with a mean of 0.94 mg/L and a median of 0.80 mg/L. For ground water plants, values ranged from 0 to 5 mg/L with a mean of 0.88 mg/L and a median of 0.33 mg/L (WIDB, 1990).

Five national surveys reported residual levels for chlorine in U.S. drinking water. The American Water Works Association's (AWWA) 1991 Disinfection survey collected data from a total of 283 utilities. Each facility was asked to respond to questions involving disinfection and quality control. Based on the survey results, mean free chlorine residuals in drinking water entering distribution systems were found to range from 0.07 to 5.00 mg/L, with a median of 1.10 mg/L (AWWA, 1991).

Regional/Local Studies

In 1988, four surface water treatment plants participated in full plant studies of various disinfection schemes. During the employment of chlorine disinfection, the average free chlorine residual for each of three plants was 0.63 mg/L, 0.8 mg/L, and 0.30 mg/L. For the two plants which used a combination of chlorine and ozone, the average residuals were determined to be 0.52 mg/L and 0.2 mg/L (Jacangelo et al., 1989).

In a survey of Kansas ground water supplies in 1986, finished water samples from 31 public supplies were analyzed for free chlorine. Concentrations ranged from 0.2-4.0 mg/L, with a mean of 1.6 mg/L and a median of 1.3 mg/L from 50 samples (Miller et al., 1990).

In a 1983 survey of 12 full-scale treatment plants from six states, finished water from one of the plants reportedly had a chlorine residual value of 1.8 mg/L at the entry point to the distribution system. Two finished water samples from the plant's distribution system contained values of 1.3 mg/L and 0.2 mg/L (Singer and Chang, 1989).

Uden and Miller (1983) reported residual chlorine levels in drinking of Amherst, Massachusetts. Two sets of tap water samples were collected from each of Amherst's two treatment plants, with the first set of samples analyzed immediately following collection and the second set allowed to sit for 24 hours to mimic distribution levels. The first set of samples from each plant had a level 3 mg/L. After 24 hours, however, residual chlorine was detected in samples from only one of the plants. The lack of residual was attributed to the natural high organic content of source waters.

Several studies conducted in 1978 and 1979 analyzed drinking water for chlorine residual. In New York State, 5 samples from distribution systems of three treatment plants had values ranging from <0.1-1.2 mg/L, with a median of 0.4 mg/L. The mean of the positives was 0.5 mg/L (Schreiber, 1981). Thirteen surface water plants from nine of the larger cities in North Carolina had an average residual of 1.5 mg/L in their finished water (Singer et al., 1981). At the University of Iowa water treatment plant, a residual concentration of 1.5-2.5 mg/L was reported (Schnoor et al., 1979).

Drinking water from 19 chlorinated surface water supplies in Massachusetts were sampled for free chlorine residual in a 1976 survey conducted by the state of Massachusetts Department of the Environment. Finished water samples collected at the plant had a free residual of 0.3-4.0 mg/L, with a mean of 1.3 mg/L. In the distribution system, the free residual chlorine ranged from 0-2.0 mg/L and the mean was 0.2 mg/L (Moore et al., 1981)

Non-Drinking Water

No information was found describing the occurrence of chlorine in ambient water.

3.2 Chloramine

Chloramine is used as a chemical intermediate in the manufacture of hydrazine and as a disinfectant. In the disinfection of drinking water, it is used to control taste and odor problems, limit the formation of chlorinated disinfection byproducts, and maintain a residual in the distribution system for controlling biofilm growth. At typical pHs of most drinking waters the predominant chloramine specie is monochloramine. In the environment, monochloramine is persistent, with first-order decay constants of 0.03 to 0.075 hr⁻¹ in laboratory experiments and 0.28 to 0.31 hr⁻¹ in outdoor chlorinated effluents. In receiving waters, monochloramine is

expected to decompose more rapidly, probably through the formation of NHBrCl and decomposition of the dihalamine. The half-life of monochloramine in water varies with pH and salinity. At pH 7 and 25°C, the half-life of monochloramine is 6 hr at 5 parts per thousand (ppt) salinity and 0.75 hr at 35 ppt salinity; at pH 8.5 and 25°C, the half-life is 188 hr at 5 ppt salinity and 25 hr at 35 ppt salinity. Monochloramine is expected to decompose in wastewater discharges to receiving waters via chlorine transfer to organic nitrogen-containing compounds (Johnson and Jensen, 1986; Jolley and Carpenter, 1982; Norman et al., 1980).

Chloramine occurs in drinking water both as a by-product and intentionally for disinfection. Chloramine is formed as a by-product of chlorination when source waters contain ammonia. It is also used as a primary or secondary disinfectant, usually with chloramine being generated on site by the addition of ammonia to water following treatment by chlorination. The use of chloramines has been shown to reduce the formation of certain by-products, notably trihalomethanes, relative to chlorination alone. Chlorination by-product formation can be minimized when the ammonia is added prior to or in combination with chlorine by reducing the chlorine residual of the water being treated. In some plants, however, ammonia may be added some time after the addition of chlorine, allowing the chlorine residual to react with precursor chemicals (Bull and Kopfler, 1990; USEPA, 1980b; Cooper et al., 1985).

Based on the Water Industry Data Base (WIDB) data, it has been estimated that 29% of community surface water systems and 11% of community ground water systems, serving greater than 10,000 people, use chloramines for disinfection in the United States. There are only a few community systems serving less than 10,000 people that are expected to use chloramine. It is estimated that from systems serving greater than 10,000 people, 56.5 million people served by surface and 7.8 million people served by ground water systems are exposed to chloramines from disinfection (WIDB, 1990).

Drinking Water

National Studies

In 1987, the American Water Works Association Research Foundation (AWWARF) sponsored a national survey of trihalomethanes (THMs) conducted by the Metropolitan Water District of Southern California. As part of this survey, alternate treatment technologies were investigated which would achieve lower THM levels. Based on survey results, typical chloramine concentrations used in drinking water were found to be 1.5 mg/L for systems using lakes and 2.7 mg/L for systems using flowing streams as their raw water sources (McGuire and Meadow, 1988).

Regional/Local Studies

The Metropolitan Water District of California changed its primary disinfectant to chloramines in 1984 to ensure compliance with trihalomethane regulations. Its treatment plants are operated at a chlorine to ammonia-nitrogen ratio of 3:1. The total ammonia-nitrogen dose

was 0.5 mg/L and the chlorine dose was adjusted to result in a total chloramine residual, primarily monochloramine, of 1.5 mg/L (Krasner et al., 1989a).

Non-Drinking Water

No information was found concerning chloramine occurrence in ambient water. Because chloramine is found in drinking water due to its uses as a disinfectant and a by-product of disinfection, it is not expected to be found in significant quantities in raw water sources.

3.3 Chlorine Dioxide, Chlorate, and Chlorite

Chlorine dioxide is used in a variety of industrial applications due to its strong oxidizing characteristics. In the treatment of drinking water, chlorine dioxide is used as a primary and secondary disinfectant. As a bleaching agent, it is used to bleach paper-pulp, flour, cellulose, fats and oils, leather, textiles, and beeswax. In addition, it is used in cleaning and detanning leather, manufacturing chlorite salts, as an oxidizing agent, bactericide, and an antiseptic. Chlorine dioxide is a strong oxidizer that does not react with organics in the water, as does chlorine, to produce by-products such as the trihalomethanes. It is fairly unstable and rapidly dissociates into chlorite and chlorate in water. This dissociation is also reversible with chlorite converting back to chlorine dioxide. Chlorite ion is the primary product of chlorine dioxide reduction. Formation of chlorate occurs at lower levels than chlorite, depending on pH and sunlight (Merck Index, 1989).

Chlorite, as the sodium salt, is used in the on-site production of chlorine dioxide and as a bleaching agent by itself, for paper-pulp, textiles, and straw. Chlorite is also used to manufacture waxes, shellacs, and varnishes. Chlorate, as the sodium salt, was once used as a defoliant, to tan leather, and to manufacture dyes, matches, and explosives.

Chlorine dioxide is used by water treatment plants as a disinfectant and in combination with chlorine to combat taste, odor, and color problems in drinking water. Chlorine dioxide used to treat water is most commonly generated from the reaction of chlorite and chlorine. Chlorite and chlorate occurrence in drinking water result from the dissociation of chlorine dioxide in water (Anderson et al., 1982; White, 1986).

Based on the information derived from the AWWA Water Industry Data Base (WIDB), it has been estimated that approximately 10% of surface water plants and 1% of ground water plants, serving more than 10,000 people, currently use chlorine dioxide for disinfection in the United States. It is assumed that none of the plants serving fewer than 10,000 people use chlorine dioxide. It is estimated that from these plants serving greater than 10,000 people, 12.4 million people served by surface and 0.2 million people served by ground water plants are exposed to chlorine dioxide from disinfection (WIDB, 1990).

Drinking Water

National Studies

The EPA's Technical Support Division (TSD) has compiled a database of its disinfection by-products field studies. The studies included an occurrence of chlorite and chlorate in drinking water from a survey conducted from August 1991 to September 1991. In plants using chlorine dioxide, chlorite concentrations in four finished water samples ranged from 15 to 740 $\mu\text{g/L}$, with a mean of 240 $\mu\text{g/L}$ and a median of 110 $\mu\text{g/L}$. Chlorate concentrations, in four finished water samples from plants using chlorine dioxide, ranged from 21 to 330 $\mu\text{g/L}$, with a mean and median of 200 $\mu\text{g/L}$ and 220 $\mu\text{g/L}$, respectively. For plants not using chlorine dioxide, chlorate was measured in 30 finished water samples and 4 distribution samples. Concentrations ranged from <10-660 $\mu\text{g/L}$ in finished water samples and the mean and median were 87 $\mu\text{g/L}$ and 16 $\mu\text{g/L}$, respectively. Distribution samples were found to have a mean concentration of 18 $\mu\text{g/L}$, a median of 13 $\mu\text{g/L}$, and a range of <10-47 $\mu\text{g/L}$ (TSD, 1992).

In 1987, the American Water Works Association Research Foundation (AWWARF) sponsored a national survey of trihalomethanes (THMs) conducted by the Metropolitan Water District of Southern California. As part of this survey, alternate treatment technologies were investigated which would achieve lower THM levels. Based on survey results, typical chlorine dioxide dosage used in drinking water were found to be 0.6 mg/L for systems using lakes and 1.0 mg/L for systems using flowing streams as their raw water sources (McGuire and Meadow, 1988).

Regional/Local Studies

Limited information was available concerning chlorine dioxide, chlorate, and chlorite occurrence in drinking water. However, Bull and Kopfler (1990) cited results from three different studies which reported information concerning the occurrence of the three chemicals in drinking water. The first of these was a pilot plant study by Lykins and Griesse (1986 in Bull and Kopfler, 1990) in which Ohio River water was dosed with 1.6 mg/L of chlorine dioxide. Resulting chlorite and chlorate concentrations were 0.3-0.5 mg/L and 1.5-2.0 mg/L, respectively. Masschelein (1989 in Bull and Kopfler, 1990) reported that 40-60% of chlorine dioxide used in water disinfection is converted to chlorite in finished water. Depending on the conditions of disinfection, this percentage ranged from 50-100%. Gordon et al. (1990 in Bull and Kopfler, 1990) found from their own literature review that the chlorite yield was 70% of the chlorine dioxide dosage used. In addition, they suggested that doses of 4-6 mg/L of chlorine dioxide may be necessary for disinfection. Based on this information, Bull and Kopfler (1990) estimated that chlorite concentrations in finished drinking water may be as low as 0.1 mg/L and as high as 2-3 mg/L, with concentrations as high as 10 mg/L in plants where the conditions are poorly controlled.

Miltner (1977 in Stevens, 1982) reported results from a study designed to determine the relative proportions of chlorite and chlorate formed from disinfection with chlorine dioxide. A chlorine dioxide dose of 1.5 mg/L was applied to Ohio River water that was treated at a pilot

plant. Results indicated that of the original chlorine dioxide added, approximately 50% was converted to chlorite (0.7 mg/L), 25% to chlorate (0.4 mg/L), and 25% to chloride (0.3 mg/L).

Non-Drinking Water

No information was found concerning the occurrence of chlorine dioxide, chlorate, and chlorite in drinking water.

4. Disinfection By-Products

4.1 Bromate

Bromate, in its salt form, is a white crystal that is highly soluble in water. In the form of sodium bromate, it can be used with sodium bromide to extract gold from gold ores. Bromate is also used to clean boilers and in the oxidation of sulfur and vat dyes. In the food industries, bromate is used as a maturing agent in malted beverages, as a dough conditioner, and in confectionery products (Merck Index, 1989).

Bromate (BrO_3^-) occurs in public water systems that treat raw water containing bromide and other organobromine compounds with ozone. Bromide and organobromine compounds occur in raw waters from both natural and anthropogenic sources. Bromide can be oxidized to bromate or hypobromous acid; however, in the presence of excess ozone bromate is the principal product. In laboratory studies, the rate and extent of bromate formation depends on the ozone concentration used in disinfection, pH, and contact time. Bromate also may be produced during chlorination reactions; however, under conditions normally found in drinking water, bromate formation is expected to be limited (Glaze, 1988; Singer, 1988; Cooper, et al., 1985).

Drinking Water

National Studies

The EPA's Technical Support Division (TSD) has compiled a database of its disinfection by-products field studies. The studies included an occurrence of bromate in drinking water from a survey conducted from August to September 1991. The study analyzed four drinking water samples from plants not using ozone; however, bromate concentrations were not found above the detection limit of 10 $\mu\text{g/L}$ (TSD, 1992).

Regional/Local Studies

In an American Water Works Association (AWWA) study of the effect of coagulation and ozonation on the formation of disinfection by-products, bromate levels were measured in 18 raw and 6 coagulated-settled waters. Overall, bromate levels increased with increased ozone residual. Bromate formation did not start until the organic demand of the water was exhausted and an ozone residual was present (AWWA, 1992).

With initial bromide concentrations of $<0.2 \text{ mg/L}$, bromate formation was less than 15 $\mu\text{g/L}$. In general, for an ozone residual $\leq 1 \text{ mg/L}$ and a bromide concentration $< 1.13 \text{ mg/L}$, the bromate level was lower than 40 $\mu\text{g/L}$. Appreciable levels of bromate, however, formed water in water with low bromide waters and low ozone residual. In waters with high bromide levels, levels of 5-30 $\mu\text{g/L}$ were formed with an ozone residual less than 0.05 mg/L . Also, bromate levels were substantially lower for ozonated waters with a pH less than 7.0 (AWWA, 1992).

Non-Drinking Water

No information was found concerning the occurrence of bromate in natural waters. Because bromate occurs in drinking water as a by-product of disinfection, it is not expected to be found in significant quantities in raw water sources.

4.2 Chloral Hydrate

Chloral hydrate (CH), also known as trichloroacetaldehyde monohydrate, is used as a hypnotic or sedative drug in humans and is also used in the manufacture of DDT. CH has been found to occur as a disinfection by-product in public water systems that chlorinate water containing humic and fulvic acids. Ozonation prior to chlorination has been found to increase the levels of CH compared to chlorine disinfection alone. Also, preozonation followed by chloramines produces levels of CH below that of chlorine disinfection (Jacangelo et al., 1989; Merck Index, 1989).

Drinking Water

National Studies

Two studies describe the occurrence of CH in the nation's drinking water. Case studies of 35 water utilities nationwide, of which 10 were located in California, sampled for CH in the clearwell effluent. Samples were taken for four quarters (spring, summer, and fall in 1988 and winter in 1989). The median for all four quarters was 2.1 $\mu\text{g/L}$, with the medians of the individual quarters ranging from 1.7 to 3.0 $\mu\text{g/L}$. The maximum value found was 22 $\mu\text{g/L}$. For all four quarters, 75% of the CH levels were below 4.1 $\mu\text{g/L}$. The detection limits for the survey were 0.02 $\mu\text{g/L}$ in the first quarter and 0.1 $\mu\text{g/L}$ thereafter (Krasner et al., 1989b; USEPA and AMWA, 1989).

The EPA's Technical Support Division (TSD) has compiled a database on data from its disinfection by-products field studies. The studies included a chlorination by-products survey, conducted from October 1987 to March 1989. In this survey, CH was sampled in finished water at the treatment plant and in the distribution system. Out of 67 finished water samples taken at the plant, concentrations ranged from <0.2-25 $\mu\text{g/L}$, with a mean of 5.0 $\mu\text{g/L}$ and a median of 2.5 $\mu\text{g/L}$. In 53 distribution system samples, concentrations ranged from <0.2-30 $\mu\text{g/L}$, with a mean and median of 7.8 $\mu\text{g/L}$ and 4.4 $\mu\text{g/L}$, respectively (TSD, 1992).

Regional/Local Studies

No local or regional studies were found which document the occurrence of CH in drinking water.

Non-Drinking Water

No information was found concerning CH occurrence in ambient water. Because CH is found in drinking water as a by-product of disinfection, it is not expected to be found in significant quantities in raw water sources.

4.3 Dichloroacetic acid

Dichloroacetic acid (DCAA) occurs in drinking water as a by-product of disinfection. In industry, it is used as a chemical intermediate and in the manufacture of pharmaceuticals and has been used as an agricultural fungicide, and a topical astringent. Its medical uses include experimental treatment of diabetes and hypercholesterolemia and is being investigated for possible uses as a hypoglycemic, hypolactemic, and hypolipidemic agent (Merck Index, 1989).

DCAA has been found to occur as a disinfection by-product in public water systems that chlorinate water containing humic and fulvic acids. Similar to other chlorination by-products (such as the Trihalomethanes), DCAA levels can be reduced, though not eliminated, when chloramines are used to disinfect. The reduction is less, however, when chloramination involves a pre-chlorination step where a free chlorine residual is maintained through a portion of the water treatment process prior to the addition of ammonia.

Drinking Water

National Studies

Case studies of 35 water utilities nationwide, of which 10 were located in California, sampled for DCAA in the clearwell effluent. Samples were taken for four quarters (spring, summer, and fall in 1988 and winter in 1989). The median for all four quarters was 6.4 $\mu\text{g/L}$, with the medians of the individual quarters ranging from 5.0-7.3 $\mu\text{g/L}$. The maximum value found was 46 $\mu\text{g/L}$. For all four quarters, 75% of the data was below 12 $\mu\text{g/L}$. The detection limit for the survey was 0.6 $\mu\text{g/L}$ (Krasner et al., 1989b; USEPA and AMWA, 1989).

The EPA's Technical Support Division (TSD) has compiled a database on data from its disinfection by-products field studies. The studies included a chlorination by-products survey, conducted from October 1987 to March 1989. In this survey, DCAA was sampled in finished water at the treatment plant and in the distribution system. For surface water systems, the mean concentration in finished water for systems serving above and below 10,000 people was 20.7 $\mu\text{g/L}$ and 21.8 $\mu\text{g/L}$, with the 90th percentile of 33.4 $\mu\text{g/L}$ and 50.0 $\mu\text{g/L}$ for 42 samples and 20 samples, respectively. In the distribution system, the mean was 22.1 $\mu\text{g/L}$ and 27.7 $\mu\text{g/L}$ for plants serving above and below 10,000, with the 90th percentile concentration of 48.0 $\mu\text{g/L}$ and 41.0 $\mu\text{g/L}$ for 39 samples and 11 samples, respectively. The ground water systems serving less than 10,000 had a mean DCAA concentration in finished water samples and distribution system samples, respectively, of 2.7 $\mu\text{g/L}$ and 1.9 $\mu\text{g/L}$ for 7 observations and 5 observations, with the 90th percentile of 12.5 $\mu\text{g/L}$ and 4.7 $\mu\text{g/L}$. For systems serving greater than 10,000, DCAA was

not detected in single samples taken at the plant and from the distribution system based on a detection limit of 0.4 $\mu\text{g/L}$ (TSD, 1992).

Regional/Local Studies

Uden and Miller (1983) analyzed drinking water from two Massachusetts treatment plants. DCAA concentrations were at 63.1 $\mu\text{g/L}$ and 123 $\mu\text{g/L}$ immediately after disinfection and 79.5 $\mu\text{g/L}$ and 133 $\mu\text{g/L}$ after standing for 24 hours, respectively. Singer and Chang (1989) reported that the mean for DCAA in the distribution systems for six utilities was 47 $\mu\text{g/L}$, with a range of 8-79 $\mu\text{g/L}$.

Fair et al. (1988) analyzed drinking water from three community water supplies for chlorination by-products. DCAA concentrations reported for each of the plants ranged from 5.9-32 $\mu\text{g/L}$ in finished water at the plants and from 8.9-58 $\mu\text{g/L}$ in the distribution systems.

Non-Drinking Water

No information was found concerning the occurrence of DCAA in natural waters. Because DCAA occurs in drinking water as a by-product of disinfection, it is not expected to be found in significant quantities in raw water sources.

4.4 Trichloroacetic acid

Trichloroacetic acid (TCAA), a major by-product of chlorinated drinking water, is used as a pre-emergence herbicide and a reagent for synthetic medicinal products. In the laboratory it has been used to precipitate proteins. It is also used in the medical field as a peeling agent for damaged skin, cervical dysplasia, and removal of tattoos (Pringle et al., 1975; Merck Index, 1990).

TCAA occurs in public water systems that chlorinate water containing humic and fulvic acids. Similar to other chlorination by-products (such as the THMs), TCAA levels can be reduced, though not eliminated, when chloramines are used to disinfect. The reduction is less, however, when chloramination involves a pre-chlorination step where a free chlorine residual is maintained through a portion of the water treatment process prior to the addition of ammonia. In addition, it has been shown that the formation of TCAA is reduced substantially at high pH levels (i.e., around pH 9) (Stevens et al., 1989).

Drinking Water

National Studies

Case studies of 35 water utilities nationwide, of which 10 were located in California, sampled for TCAA in the clearwell effluent. Samples were taken for four quarters (spring, summer, and fall in 1988 and winter in 1989). The median for all four quarters was 5.5 $\mu\text{g/L}$,

with the medians of the individual quarters ranging from 4.0-5.8 $\mu\text{g/L}$. For all four quarters, 75% of the data was below 15.3 $\mu\text{g/L}$. The detection limit for the survey was 0.6 $\mu\text{g/L}$ (Krasner et al., 1989b; USEPA and AMWA, 1989).

The EPA's Technical Support Division (TSD) has compiled a database on data from its disinfection by-products field studies. The studies included a chlorination by-products survey conducted from October 1987 to March 1989. In this survey, TCAA was sampled for in finished water at the treatment plant and in the distribution system. For surface water systems, the mean concentration in finished water for systems serving above and below 10,000 people was 14.4 $\mu\text{g/L}$ and 14.8 $\mu\text{g/L}$, with the 90th percentile of 28.7 $\mu\text{g/L}$ and 30.4 $\mu\text{g/L}$ for 42 samples and 20 samples, respectively. In the distribution system, the mean was 17.0 $\mu\text{g/L}$ and 16.6 $\mu\text{g/L}$ for plants serving above and below 10,000, with the 90th percentile concentration of 30.6 $\mu\text{g/L}$ and 28.9 $\mu\text{g/L}$ for 39 samples and 11 samples, respectively. The ground water systems serving less than 10,000 had a mean TCAA concentration in finished water samples and distribution system samples, respectively, of 1.9 $\mu\text{g/L}$ and 1.1 $\mu\text{g/L}$ for 7 observations and 5 observations, with the 90th percentile of 10.7 $\mu\text{g/L}$ and 4.2 $\mu\text{g/L}$. For systems serving greater than 10,000, TCAA was not detected in single samples taken at the plant and from the distribution system based on a detection limit of 0.4 $\mu\text{g/L}$ (TSD, 1992).

Regional/Local Studies

Uden and Miller (1983) analyzed drinking water from two Massachusetts treatment plants. TCAA concentrations were reportedly at 33.6 and 161 $\mu\text{g/L}$ immediately after disinfection and 72.8 and 160 $\mu\text{g/L}$ after standing for 24 hours, respectively. Singer and Chang (1989) reported that the mean for TCAA in the distribution systems for six utilities was 49 $\mu\text{g/L}$, with values ranging from 15-103 $\mu\text{g/L}$.

Fair et al. (1988) analyzed drinking water from three community water supplies for chlorination by-products. TCAA concentrations reported for each of the plants ranged from <0.1-54 $\mu\text{g/L}$ in finished water at the plants and from <0.1-77 $\mu\text{g/L}$ in the distribution systems.

Non-Drinking Water

No information was found concerning the occurrence of TCAA in natural waters. Because TCAA occurs in drinking water as a by-product of disinfection, it is not expected to be found in significant quantities in raw water sources.

4.5 Chloroform

Chloroform, also known as trichloromethane, is a nonflammable, colorless liquid with a sweet odor. It appears to be a natural product of the environment as it is found in some plants. In industry, chloroform is used as a solvent, chemical intermediate, extractant, and dry cleaning agent. It is used primarily in the manufacture of fluorocarbon-22 (chlorodifluoromethane) which is used for refrigerants and fluoropolymer synthesis. Previous applications included uses as an

anesthetic, in medicinal preparations, and an ingredient of grain fumigants. Chloroform releases to the environment are primarily due to volatilization from industrial uses, however, releases to water occur from the chlorination of water and sewage and contamination of industrial effluents. Due to its poor soil adsorptivity, chloroform may also leach into groundwater from spills and other releases on land. Based on its high vapor pressure (246 mm Hg at 25 °C) and moderate water solubility (8000 mg/L at 20 °C), chloroform releases to water and land will be lost mainly by evaporation. Modeling studies indicate the volatilization half-life of chloroform in a lake, pond, and river would be 9-10 days, 40 hours, and 36 hours, respectively. Chloroform adsorbs poorly to sediments and can be biodegraded in water and soil (Howard, 1990).

Chloroform, the most prevalent trihalomethane in drinking water, occurs in public water systems from the chlorination of drinking water and from the contamination of source water from industrial uses. Chloroform is a by-product of the chlorination of naturally occurring organic matter in raw water. Several water quality factors affect the formation of chloroform including Total Organic Carbon (TOC), pH, and temperature. Surface water systems have higher frequencies of occurrence and higher concentrations of chloroform than ground water systems because humic and fulvic material are found primarily in surface water sources. Since residual chlorine levels are maintained in water distribution systems for disinfection purposes, the formation of chloroform continues throughout the distribution system (Stevens and Symons, 1977; USEPA, 1980b).

Different treatment practices affect the formation of chloroform. The levels of chloroform can be reduced, though not eliminated, when chloramines are used to disinfect. The reduction is less, however, when chloramination involves a pre-chlorination step where a free chlorine residual is maintained through a portion of the water treatment process prior to the addition of ammonia. Preozonation followed by chloramines substantially reduces the formation of chloroform. Also, the use of chlorine dioxide is expected to produce lower levels of chloroform than chlorine (USEPA, 1980b).

According to the EPA's Toxic Release Inventory, the total release of chloroform to environmental media, due to manufacturing in 1988, was 26,604,039 lbs. A total of 1,094,443 lbs. was released to surface waters of 0.43% of the total release (USEPA, 1990).

Drinking Water

National Studies

Eight surveys were found which describe the national occurrence of chloroform in drinking water. In 1975, the National Organics Reconnaissance Survey (NORS), conducted by the EPA, collected drinking water samples from 80 cities nationwide. The survey sampled for several organics including trihalomethanes at the water treatment facilities. Eighty percent of the systems had surface water sources and the remaining 20% had ground water sources. The median concentration for chloroform was 23 µg/L and the maximum level found was 311 µg/L. NORS was performed prior to the Total Trihalomethane regulation; therefore, these results may be higher than current levels (Symons et al., 1975).

The National Organics Monitoring Survey (NOMS) was conducted by the EPA from March 1976 to January 1977. In NOMS, 113 community water supplies were sampled at the treatment plants during three phases. Surface water was the major source for 92 of the systems and ground water was the major source for the remaining 21 systems. Two analytical methods were employed that measured the chloroform concentrations at the time of sampling and measured the maximum chloroform concentrations due to the reaction of all the chlorine residual. Chloroform was detected, over the three phases, in 92% to 100% of the systems sampled. The median concentrations of the three phases ranged from 22-54.5 $\mu\text{g/L}$. The maximum value found was 540 $\mu\text{g/L}$. NOMS was conducted before the enactment of the Total Trihalomethane regulation; therefore, these results may be higher than current levels (Bull and Kopfler, 1990).

The Community Water Supply Survey (CWSS) was conducted by the EPA in 1978. The survey examined over 1,100 samples representing over 450 water supply systems. The samples were taken at the treatment plants and in the distribution systems. In the CWSS, 97% of the surface water supplies and 34% of the ground water supplies were positive for chloroform. For surface water supplies the mean of the positives and the overall median were 90 $\mu\text{g/L}$ and 60 $\mu\text{g/L}$, respectively. The mean of the positives, for ground water supplies, was 8.9 $\mu\text{g/L}$ and the overall median was below the minimum reporting limit of 0.5 $\mu\text{g/L}$ (Brass et al., 1981).

The Rural Water Survey (RWS) was conducted between 1978 and 1980, by the EPA, to evaluate the status of drinking water in rural America. Samples from over 2,000 households, representing more than 600 rural water supply systems, were examined. In the RWS, 82% of the surface water supplies and 17% of the ground water supplies were positive for chloroform. For the surface water supplies the mean of the positives and the overall median concentrations were 84 $\mu\text{g/L}$ and 57 $\mu\text{g/L}$, respectively. For the ground water supplies the mean of the positives was 8.9 $\mu\text{g/L}$ and the overall median was below the minimum reporting limit of 0.5 $\mu\text{g/L}$ (Brass, 1981).

The Ground Water Supply Survey (GWSS) was conducted from December 1980 to December 1981, by the EPA, to develop data on the occurrence of volatile organic chemicals in ground water supplies. Out of a total of 945 ground water systems, 466 systems were chosen at random, while the remaining 479 systems were chosen on the basis of location near industrial, commercial, and waste disposal activities. Samples were collected at or near the entry to the distribution system. For chloroform, the median of the positives for the randomly chosen systems serving above and below 10,000 people were 1.4 $\mu\text{g/L}$ and 1.6 $\mu\text{g/L}$ with the occurrence rate of 37.1% and 57%, respectively. The non-randomly chosen systems had a median of the positives of 1.9 $\mu\text{g/L}$ and an occurrence rate of 53.2%. The maximum values for systems, random and non-random, serving above and below 10,000 were 300 $\mu\text{g/L}$ and 430 $\mu\text{g/L}$, respectively. The 90th percentile for chloroform in systems serving less than 10,000 people was 7.8 $\mu\text{g/L}$ and in systems serving greater than 10,000 it was 17 $\mu\text{g/L}$ (Westrick et al., 1983).

The Technical Support Division (TSD) of the Office of Ground Water and Drinking Water (OGWDW) maintains an unregulated contaminant database. For chloroform, the database contains 5,806 samples taken at the treatment facilities from nineteen states between 1984 and

1991. The mean and median concentrations were determined to be 17 $\mu\text{g/L}$ and 5 $\mu\text{g/L}$, respectively (TSD, 1991).

Case studies of 35 water utilities nationwide, of which 10 were located in California, sampled for chloroform in the clearwell effluent. Samples were taken for four quarters (spring, summer, and fall in 1988 and winter in 1989). The median for all four quarters was 14 $\mu\text{g/L}$ with the medians of the individual quarters ranging from 9.6-15 $\mu\text{g/L}$. The maximum value found was 130 $\mu\text{g/L}$. For all four quarters, 75% of the data was below 33 $\mu\text{g/L}$ (Krasner et al., 1989b; USEPA and AMWA, 1989).

The EPA's Technical Support Division (TSD) has compiled a database on data from its disinfection by-products field studies. The studies included a chlorination by-products survey, conducted from October 1987 to March 1989. In this survey, chloroform was sampled for in finished water at the treatment plant and in the distribution system. For surface water systems, the mean concentration in finished water for systems serving above and below 10,000 people was 38.9 $\mu\text{g/L}$ and 42.8 $\mu\text{g/L}$, with the 90th percentile of 74.4 $\mu\text{g/L}$ and 63.5 $\mu\text{g/L}$ for 42 samples and 20 samples, respectively. In the distribution system, the mean was 58.7 $\mu\text{g/L}$ and 77.2 $\mu\text{g/L}$ for plants serving above and below 10,000, with the 90th percentile concentration of 141.0 $\mu\text{g/L}$ and 110.0 $\mu\text{g/L}$ for 39 samples and 11 samples, respectively. The ground water systems serving less than 10,000 had a mean chloroform concentration in finished water samples and distribution system samples, respectively, of 2.8 $\mu\text{g/L}$ and 3.6 $\mu\text{g/L}$ for 7 observations and 5 observations, with the 90th percentile of 10.3 $\mu\text{g/L}$ and 9.4 $\mu\text{g/L}$. For a single sample from ground water systems serving greater than 10,000, the concentration at the plant and in the distribution system, respectively, was 0.6 $\mu\text{g/L}$ and 0.8 $\mu\text{g/L}$ (TSD, 1992).

Regional/Local Studies

Fair et al. (1988) analyzed drinking water from three community water supplies for chlorination by-products. Chloroform concentrations reported for each of the plants ranged from 11-100 $\mu\text{g/L}$ in finished water at the plants and from 21-160 $\mu\text{g/L}$ in the distribution systems.

The EPA's five-year Total Exposure Assessment Methodology (TEAM) study measured the personal exposures of urban populations to a number of organic chemicals in air and drinking water in several U.S. cities. As part of the study, running tap water samples, collected from residences of nearly 850 study participants during the morning and the evening, were analyzed for chloroform content. Exhibit 4.1 shows chloroform concentrations found in drinking water from the five cities surveyed.

Exhibit 4.1 Chloroform in Tap Water from the EPA TEAM study ($\mu\text{g/L}$)					
Location	Date Sampled	Sample Size	Mean	Median	Maximum
Elizabeth/Bayonne, New Jersey	Fall 1981	355	70		170
	Summer 1982	157	61		130
	Winter 1983	49	17		33
Los Angeles, CA	Winter 1984	117	14	14	
	Summer 1984	52	29	33	
Antioch/Pittsburgh, California	Spring 1984	71	42	49	
Devils Lake, North Dakota	Fall 1982	24	0.46		1.4
Greensboro, North Carolina	Fall 1982	24	43		91

Sources: Hartwell, et al., 1987
Wallace et al., 1988
Wallace et al., 1987

Uden and Miller (1983) sampled drinking water from two treatment plants in Amherst, Massachusetts. Two sets of tap water samples were collected at each plant, with the first set of samples analyzed immediately following collection and the second set allowed to sit for 24 hours to mimic distribution levels. Chloroform concentrations were reportedly at $39.6 \mu\text{g/L}$ and $87.4 \mu\text{g/L}$ immediately after disinfection and $139 \mu\text{g/L}$ and $190 \mu\text{g/L}$ after standing for 24 hours, respectively.

Howard (1990) in his literature review reported results from several additional surveys. In a Federal survey of finished water supplies, chloroform was found to occur in 70.3% of ground water supplies (Dyksen and Hess, 1982 in Howard, 1990). Coleman et al. (1976 in Howard, 1990) reported that a survey of drinking water of five-cities found concentrations ranging from 1-301 $\mu\text{g/L}$. Drinking water from nine U.S. cities contained chloroform in 88.9% of the samples, with concentrations ranging from not detected to 57 $\mu\text{g/L}$ and a mean of the positives of 10.4 $\mu\text{g/L}$ (Heikes and Hopper, 1986 in Howard, 1990). Furlong and Ditri (1986 in Howard, 1990) reported that a survey of chlorinated drinking water from 40 plants in Michigan had a detection rate of 80%, with a range of not detected to 201.4 $\mu\text{g/L}$. The mean of the positives was 33.4 $\mu\text{g/L}$ and the median was 16.7 $\mu\text{g/L}$.

Non-Drinking Water

The National Screening Program for Organics in Drinking Water (NSP), sponsored by the EPA, was conducted from June 1977 to March 1981. The survey sampled 169 systems

nationwide. Raw water samples were collected at the treatment facilities. In surface water supplies, the mean and median chloroform concentration for 67 positives were 2.2 $\mu\text{g/L}$ and 0.2 $\mu\text{g/L}$, respectively, with a maximum concentration of 75 $\mu\text{g/L}$. In ground water supplies, three positive detections had a mean concentration of 0.2 $\mu\text{g/L}$, while supplies using a mixture of surface and ground water had a mean of 0.3 $\mu\text{g/L}$ for 8 positive detections (Boland, 1981).

The EPA's 1975 National Organic Reconnaissance Survey (NORS), sampled raw water sources of 80 U.S. water supplies. Of these 80 supplies, 16 had ground water sources and 64 had surface water sources. Based on the survey's results, chloroform was detected in raw water samples from 23 systems with the mean of the positives found to be 0.4 $\mu\text{g/L}$. Overall, concentrations ranged from not detected to 1 $\mu\text{g/L}$, with the detection limit varying from 0.1-0.2 $\mu\text{g/L}$ (Symons et al., 1975).

Three additional surveys were found which analyzed groundwater for chloroform content. The largest of these surveys collected samples from 1174 community wells and 617 private wells throughout the state of Wisconsin. As of June 1984, chloroform was detected in 1.1% of the community wells and 0.32% of the private wells (Krill and Sonzogni, 1986 in Howard, 1990). The Arizona Department of Environmental Quality conducted a random survey of Arizona community water supply wells as part of an effort to determine the baseline water quality of its groundwater supplies. A total of 40 wells from 38 systems, serving 1,000 or more people, were sampled from July to September 1986, with 16 of the wells resampled in January of 1987. Chloroform concentrations were measured at a maximum concentration of 3.3 $\mu\text{g/L}$ (Ellingson and Redding, 1988). In a survey of groundwaters in New Jersey, conducted from 1977 to 1979, chloroform concentrations ranged from 67-490 $\mu\text{g/L}$ (Burmester, 1982 in Howard, 1990).

Several studies were found which analyzed surface waters for chloroform content. Bellar et al. (1974 in Wei et al., 1985) reported that chloroform is present in lakes and streams in concentrations ranging from 0.1-0.9 $\mu\text{g/L}$. The Ohio River Valley Water Sanitation Commission (1982 in Howard, 1990) collected samples from 11 stations along the Ohio River Basin from 1980 to 1981. Chloroform was detected in 72% of the samples analyzed, with 832 samples containing concentrations between 1-10 $\mu\text{g/L}$ and 27 samples containing concentrations greater than 10 $\mu\text{g/L}$. Ewing et al. (1977 in Howard, 1990) reported that chloroform concentrations ranged from 1-120 $\mu\text{g/L}$ in samples collected from 204 sites located on 14 heavily industrialized river basins in the United States, with an occurrence rate of 79%. A survey of 30 sites on the Delaware River and its tributaries found chloroform concentrations above 1 $\mu\text{g/L}$ in 93% of its samples (DeWalle and Chian, 1978 in Howard, 1990). The Ohio River Valley Water Sanitation Commission (1980 in Howard, 1990) found chloroform in 72% of 232 Ohio River samples, with concentrations ranging from 0.1-22 $\mu\text{g/L}$.

4.6 Bromodichloromethane

Bromodichloromethane (BDCM) is a nonflammable, colorless liquid. In nature, it is biosynthesized by a variety of marine algae where it is released to seawater and eventually to the atmosphere. Commercial uses of BDCM are limited to its uses as a chemical intermediate for

organic synthesis and as a laboratory reagent. Due to its limited commercial uses, release of BDCM from its commercial production and uses is not considered significant. Releases to the environment from anthropogenic sources is predominantly the result of its formation during the chlorination of drinking, waste, and cooling waters. BDCM has a relatively high vapor pressure (50 mm Hg at 20°C) and a moderate solubility (4,700 mg/L at 22°C). Volatilization is the principal mechanism for removal of BDCM from rivers and streams, with a half-life ranging from 33 minutes to 12 days. BDCM is considered to be moderately to highly mobile in soil and therefore may leach into groundwaters. Results from laboratory screening tests indicate that biodegradation may be a significant removal process where volatilization is not possible. BDCM is not expected to adsorb significantly to soil and sediments (Koc of 53-251) (Howard, 1990).

BDCM occurs in public water systems that chlorinate water containing humic and fulvic acids and bromine that can enter source waters through natural and anthropogenic means. Several water quality factors affect the formation of BDCM including Total Organic Carbon (TOC), pH, and temperature. Surface water systems have higher frequencies of occurrence and higher concentrations of BDCM than ground water systems because organic material is found primarily in surface water sources. Since chlorine is used as a residual in water distribution systems for disinfection purposes, the formation of BDCM continues throughout the distribution system (Stevens and Symons, 1977; Cooper et al., 1985; USEPA, 1980b).

Different treatment practices affect the formation of BDCM. The levels of BDCM can be reduced, though not eliminated, when chloramines are used to disinfect. The reduction is less, however, when chloramination involves a pre-chlorination step where a free chlorine residual is maintained through a portion of the water treatment process prior to the addition of ammonia. Preozonation followed by chloramination substantially reduces the formation of BDCM, but ozonation prior to chlorination may increase the formation of BDCM. Also, the use of chlorine dioxide is expected to produce lower levels of BDCM than chlorine (Cooper et al. 1985; USEPA, 1980b).

Drinking Water

National Studies

Eight national studies surveyed United States drinking water for BDCM. In 1975, the National Organics Reconnaissance Survey (NORS), conducted by the EPA, collected drinking water samples from 80 cities nationwide. The survey sampled for several organics including trihalomethanes at the water treatment facilities. BDCM was found in 98% of the systems sampled. The median concentration for BDCM was 8 µg/L. The maximum level found was 116 µg/L. NORS was performed prior to the Total Trihalomethane regulation; therefore, these results may be higher than current levels (Symons et al., 1975).

The National Organics Monitoring Survey (NOMS) was conducted by the EPA from March 1976 to January 1977. In NOMS, 113 community water supplies were sampled during three phases. Surface water was the major source for 92 of the systems and ground water was the major source for the remaining 21 systems. Two analytical methods were employed that

measured the BDCM concentrations at the time of sampling and measured the maximum BDCM concentrations due to the reaction of all the chlorine residual. BDCM was detected, over the three phases, in over 90% of the systems sampled. The median concentrations of the three phases ranged from 5.9-14 $\mu\text{g/L}$. The maximum value found was 183 $\mu\text{g/L}$ (Bull and Kopfler, 1990).

The Community Water Supply Survey (CWSS) was conducted by the EPA in 1978. The survey examined over 1,100 samples representing over 450 water supply systems. The samples were taken at the treatment plants and in the distribution systems. In the CWSS, 94% of the surface water supplies and 33% of the ground water supplies were positive for BDCM. For surface water supplies the mean of the positives and the overall median were 12 $\mu\text{g/L}$ and 6.8 $\mu\text{g/L}$, respectively. The mean of the positives, for ground water supplies, was 5.8 $\mu\text{g/L}$ and the overall median was below the minimum reporting limit of 0.5 $\mu\text{g/L}$ (Brass et al., 1981).

The Rural Water Survey (RWS) was conducted between 1978 and 1980, by the EPA, to evaluate the status of drinking water in rural America. Samples from over 2,000 households, representing more than 600 rural water supply systems, were examined. In the RWS, 76% of the surface water supplies and 13% of the ground water supplies were positive for BDCM. For the surface water supplies the mean of the positives and the overall median concentrations were 17 $\mu\text{g/L}$ and 11 $\mu\text{g/L}$, respectively. For the ground water supplies the mean of the positives was 7.7 $\mu\text{g/L}$ and the overall median was below the minimum reporting limit of 0.5 $\mu\text{g/L}$ (Brass, 1981).

The Ground Water Supply Survey (GWSS) was conducted from December 1980 to December 1981, by the EPA, to develop data on the occurrence of volatile organic chemicals in ground water supplies. Out of a total of 945 ground water systems, 466 systems were chosen at random, while the remaining 479 systems were chosen on the basis of location near industrial, commercial, and waste disposal activities. Samples were collected at or near the entry to the distribution system. For BDCM, the median of the positives for the randomly chosen systems serving above and below 10,000 people were 1.4 $\mu\text{g/L}$ and 1.6 $\mu\text{g/L}$, with the occurrence rates of 35.7% and 54.3%, respectively. The non-randomly chosen systems had a median of the positives of 2.1 $\mu\text{g/L}$ and an occurrence rate of 50.9%. The maximum values for systems, random and non-random, serving above and below 10,000 were 110 $\mu\text{g/L}$ and 79 $\mu\text{g/L}$, respectively. The 90th percentile for BDCM in systems serving less than 10,000 people was 6.1 $\mu\text{g/L}$ and in systems serving greater than 10,000 it was 9.2 $\mu\text{g/L}$ (Westrick et al., 1983).

The Technical Support Division (TSD) of the Office of Ground Water and Drinking Water (OGWDW) maintains an unregulated contaminant database. For BDCM, the database contains 4,439 samples taken at the treatment facilities from nineteen states between 1984 and 1991. The mean and median concentrations were determined to be 5.6 $\mu\text{g/L}$ and 3 $\mu\text{g/L}$, respectively (TSD, 1991).

Case studies of 35 water utilities nationwide, of which 10 were located in California, sampled for BDCM in the clearwell effluent. Samples were taken for four quarters (spring, summer, and fall in 1988 and winter in 1989). The median for all four quarters was 6.6 $\mu\text{g/L}$,

with the medians of the individual quarters ranging from 4.1-10 $\mu\text{g/L}$. The maximum value found was 82 $\mu\text{g/L}$. For all four quarters, 75% of the data was below 14 $\mu\text{g/L}$ (Krasner et al., 1989b; USEPA and AMWA, 1989).

The EPA's Technical Support Division (TSD) has compiled a database on data from its disinfection by-products field studies. The studies included a chlorination by-products survey, conducted from October 1987 to March 1989. In this survey, BDCM was sampled for in finished water at the treatment plant and in the distribution system. For surface water systems, the mean concentration in finished water for systems serving above and below 10,000 people was 12.7 $\mu\text{g/L}$ and 17.0 $\mu\text{g/L}$, with the 90th percentile of 25.0 $\mu\text{g/L}$ and 29.5 $\mu\text{g/L}$ for 42 samples and 20 samples, respectively. In the distribution system, the mean was 17.4 $\mu\text{g/L}$ and 24.8 $\mu\text{g/L}$ for plants serving above and below 10,000, with the 90th percentile concentration of 35.3 $\mu\text{g/L}$ and 51.0 $\mu\text{g/L}$ for 39 samples and 11 samples, respectively. The ground water systems serving less than 10,000 had a mean BDCM concentration in finished water samples and distribution system samples, respectively, of 1.1 $\mu\text{g/L}$ and 2.2 $\mu\text{g/L}$ for 7 observations and 5 observations, with the 90th percentile of 2.6 $\mu\text{g/L}$ and 5.4 $\mu\text{g/L}$. For a single sample from ground water systems serving greater than 10,000, the concentration at the plant and in the distribution system, respectively, was 0.2 $\mu\text{g/L}$ and 0.4 $\mu\text{g/L}$ (TSD, 1992).

Regional/Local Studies

Fair et al. (1988) analyzed drinking water from three community water supplies for chlorination by-products. BDCM concentrations reported for each of the plants ranged from 7.5-30 $\mu\text{g/L}$ in finished water and from 9.9-36 $\mu\text{g/L}$ in the distribution systems.

The EPA's five-year Total Exposure Assessment Methodology (TEAM) study measured the personal exposures of urban populations to a number of organic chemicals in air and drinking water in several U.S. cities. As part of the study, running tap water samples were collected from residences of nearly 850 study participants during the morning and the evening and analyzed for BDCM content. Exhibit 4.2 shows BDCM concentrations found in drinking water from the five cities surveyed.

Furlong and Ditri (1986 in Howard, 1990) detected BDCM in drinking water of 35 of 40 Michigan water treatment plants at a median concentration of 2.7 $\mu\text{g/L}$.

Exhibit 4.2 BDCM in Tap Water from the EPA TEAM study ($\mu\text{g/L}$)					
Location	Date Sampled	Sample Size	Mean	Median	Maximum
Elizabeth/Bayonne, New Jersey	Fall 1981	355	14		23
	Summer 1982	157	14		54
	Winter 1983	49	5.4		16
Los Angeles, CA	Winter 1984	117	11	12	
	Summer 1984	52	20	24	
Antioch/Pittsburg, California	Spring 1984	71	21	17	
Devils Lake, North Dakota	Fall 1982	24	0.21		1.0
Greensboro, North Carolina	Fall 1982	24	7.1		11

Sources: Hartwell, et al., 1987
Wallace et al., 1988
Wallace et al., 1987

Non-Drinking Water

The National Screening Program for Organics in Drinking Water (NSP), sponsored by the EPA, was conducted from June 1977 to March 1981. The survey sampled 169 systems nationwide. Raw water samples were collected at the treatment facilities. In surface water supplies, the mean and median BDCM concentration for 23 positives were 2.8 $\mu\text{g/L}$ and 0.4 $\mu\text{g/L}$, respectively, with a maximum concentration of 37 $\mu\text{g/L}$. In one ground water supply sample BDCM was found at 0.1 $\mu\text{g/L}$, while one sample from a supply using a mixture of surface and ground water contained a level of 0.5 $\mu\text{g/L}$ (Boland, 1981).

Two additional surveys were found which analyzed groundwater for BDCM. The Arizona Department of Environmental Quality conducted a random survey of Arizona community water supply wells as part of an effort to determine the baseline water quality of its groundwater supplies. A total of 40 wells from 38 systems, serving 1,000 or more people, were sampled from July to September 1986, with 16 of the wells resampled in January 1987. BDCM concentrations were measured at a maximum concentration of 0.8 $\mu\text{g/L}$ (Ellingson and Redding, 1988). Fusillo et al. (1985 in Howard, 1990) analyzed 315 wells in the Potomac-Raritan-Magothy aquifer, adjacent to the Delaware River, for organic chemicals. BDCM was one of 27 organic chemicals identified.

Several studies were found which analyzed surface waters for BDCM. The Ohio River Valley Water Sanitation Commission (1982 in Howard, 1990) collected samples from 11 stations along the Ohio River Basin from 1980 to 1981. BDCM was detected in 20.9% of the 4,972 samples analyzed, with most concentrations between 0.1-1.0 $\mu\text{g/L}$. Ewing et al. (1977 in Howard, 1990) reported that surface water from 204 sites located on 14 heavily industrialized river basins in the United States was analyzed for BDCM. BDCM was detected at 24 sites, with levels between 1-12 $\mu\text{g/L}$. In 1981, BDCM was found at levels ranging from trace-0.025 $\mu\text{g/L}$ and not detected-0.02 $\mu\text{g/L}$ at 16 stations on the Niagara River and 95 stations on Lake Ontario, respectively (Kaiser et al., 1983 in Howard, 1990).

4.7 Dibromochloromethane

Dibromochloromethane (DBCM) is a nonflammable, colorless liquid. In nature, it is biosynthesized by a variety of marine algae where it is released to seawater and eventually to the atmosphere. Commercial uses of DBCM are limited to its uses as a chemical intermediate for organic synthesis and as a laboratory reagent. Due to its limited commercial uses, release of DBCM from its commercial production and uses is not considered significant. Releases to the environment from anthropogenic sources is predominantly the result of its formation during the chlorination of drinking, waste, and cooling waters. DBCM has a relatively high vapor pressure (76 mm Hg at 20 °C) and a moderate solubility (4,400 mg/L at 22°C). Volatilization is the principal mechanism for removal of DBCM from rivers and streams, with a half-life ranging from 43 minutes to 16.6 days. DBCM is considered to be moderately to highly mobile in soil and therefore may leach into groundwaters. Results from laboratory screening tests indicate that biodegradation may be a significant removal process where volatilization is not possible. DBCM is not expected to adsorb significantly to soil and sediments (Koc of 95-468) (Howard, 1990).

DBCM occurs in public water systems that chlorinate water containing humic and fulvic acids and bromine that can enter source waters through natural and anthropogenic means. Several water quality factors affect the formation of DBCM including Total Organic Carbon (TOC), pH, and temperature. Surface water systems have higher frequencies of occurrence and higher concentrations of DBCM than ground water systems because humic and fulvic material are found primarily in surface water sources. Since chlorine is used as a residual in water distribution systems for disinfection purposes, the formation of DBCM continues throughout the distribution systems (Stevens and Symons, 1977; USEPA, 1980b; Cooper et al., 1985).

Different treatment practices affect the formation of DBCM in drinking water. The levels of DBCM can be reduced, though not eliminated, when chloramines are used to disinfect. The reduction is less, however, when chloramination involves a pre-chlorination step where a free chlorine residual is maintained through a portion of the water treatment process prior to the addition of ammonia. Preozonation followed by chloramination substantially reduces the formation of DBCM, but ozonation prior to chlorination may increase the formation of DBCM. Also, the use of chlorine dioxide is expected to produce lower levels of DBCM than chlorine (USEPA, 1980b; Cooper et al., 1985).

Drinking Water

National Studies

Eight national studies surveyed United States drinking water for DBCM. In 1975, the National Organics Reconnaissance Survey (NORS), conducted by the EPA, collected drinking water samples from 80 cities nationwide. The survey sampled for several organics including trihalomethanes at the treatment facilities. DBCM was found in 90% of the systems sampled. The median concentration for DBCM was 2 $\mu\text{g/L}$. The maximum level found was 100 $\mu\text{g/L}$. NORS was performed prior to the Total Trihalomethane regulation; therefore, these results may be higher than current levels (Symons et al., 1975).

The National Organics Monitoring Survey (NOMS) was conducted by the EPA from March 1976 to January 1977. In NOMS, 113 community water supplies were sampled during three phases. Surface water was the major source for 92 of the systems and ground water was the major source for the remaining 21 systems. Two analytical methods were employed that measured the DBCM concentrations at the time of sampling and measured the maximum DBCM concentrations due to the reaction of all the chlorine residual. DBCM was detected, over the three phases, in 73% of the systems sampled. The median concentrations of the three phases ranged from under the detection limit to 3 $\mu\text{g/L}$. The maximum value found was 280 $\mu\text{g/L}$ (Bull and Kopfler, 1990).

The Community Water Supply Survey (CWSS) was conducted by the EPA in 1978. The survey examined over 1,100 samples representing over 450 water supply systems. The samples were taken at the treatment plants and in the distribution systems. In the CWSS, 67% of the surface water supplies and 34% of the ground water supplies were positive for DBCM. For surface water supplies the mean of the positives and the overall median were 5.0 $\mu\text{g/L}$ and 1.5 $\mu\text{g/L}$, respectively. The mean of the positives, for ground water supplies, was 6.6 $\mu\text{g/L}$ and the overall median was below the minimum reporting limit of 0.5 $\mu\text{g/L}$ (Brass et al., 1981).

The Rural Water Survey (RWS) was conducted between 1978 and 1980, by the EPA, to evaluate the status of drinking water in rural America. Samples from over 2,000 households, representing more than 600 rural water supply systems, were examined. In the RWS, 56% of the surface water supplies and 13% of the ground water supplies were positive for DBCM. For the surface water supplies, the mean of the positives and the overall median concentrations were 8.5 $\mu\text{g/L}$ and 0.8 $\mu\text{g/L}$, respectively. For the ground water supplies, the mean of the positives was 9.9 $\mu\text{g/L}$ and the overall median was below the minimum reporting limit of 0.5 $\mu\text{g/L}$ (Brass, 1981).

The Ground Water Supply Survey (GWSS) was conducted from December 1980 to December 1981, by the EPA, to develop data on the occurrence of volatile organic chemicals in ground water supplies. Out of a total of 945 ground water systems, 466 systems were chosen at random, while the remaining 479 systems were chosen on the basis of location near industrial, commercial, and waste disposal activities. Samples were collected at or near the entry to the distribution system. For DBCM, the median of the positives for the randomly chosen systems

serving above and below 10,000 people were 2.1 $\mu\text{g/L}$ and 2.9 $\mu\text{g/L}$ with the occurrence rates of 31.1% and 51.6%, respectively. The non-randomly chosen systems had a median of the positives of 3.9 $\mu\text{g/L}$ and an occurrence rate of 46.3%. The maximum values for systems, random and non-random, serving above and below 10,000 were 59 $\mu\text{g/L}$ and 63 $\mu\text{g/L}$, respectively. The 90th percentile for DBCM in systems serving less than 10,000 people was 5.6 $\mu\text{g/L}$ and in systems serving greater than 10,000 it was 9.2 $\mu\text{g/L}$ (Westrick et al., 1983).

The Technical Support Division (TSD) of the Office of Ground Water and Drinking Water (OGWDW) maintains an unregulated contaminant database. For DBCM, the database contains 4,439 samples taken at the treatment facilities from nineteen states between 1984 and 1991. The mean and median concentrations were determined to be 3.0 $\mu\text{g/L}$ and 1.7 $\mu\text{g/L}$, respectively (TSD, 1991).

Case studies of 35 water utilities nationwide, of which 10 were located in California, sampled for DBCM in the clearwell effluent. Samples were taken for four quarters (spring, summer, fall in 1988 and winter in 1989). The median for all four quarters was 3.6 $\mu\text{g/L}$ with the medians of the individual quarters ranging from 2.6 to 4.5 $\mu\text{g/L}$. The maximum value found was 63 $\mu\text{g/L}$. For all four quarters, 75% of the data was below 9.1 $\mu\text{g/L}$ (Krasner et al., 1989b; USEPA and AMWA, 1989).

The EPA's Technical Support Division (TSD) has compiled a database on data from its disinfection by-products field studies. The studies included a chlorination by-products survey conducted from October 1987 to March 1989. In this survey, DBCM was sampled for in finished water at the treatment plant and in the distribution system. For surface water systems, the mean concentration in finished water for systems serving above and below 10,000 people was 4.7 $\mu\text{g/L}$ and 6.9 $\mu\text{g/L}$, with the 90th percentile of 13.8 $\mu\text{g/L}$ and 24.2 $\mu\text{g/L}$ for 42 samples and 20 samples, respectively. In the distribution system, the mean was 6.3 $\mu\text{g/L}$ and 10.4 $\mu\text{g/L}$ for plants serving above and below 10,000, with the 90th percentile concentration of 17.3 $\mu\text{g/L}$ and 35.0 $\mu\text{g/L}$ for 39 samples and 11 samples, respectively. The ground water systems serving less than 10,000 had a mean DBCM concentration in finished water samples and distribution system samples, respectively, of 0.6 $\mu\text{g/L}$ and 1.8 $\mu\text{g/L}$ for 7 observations and 5 observations, with the 90th percentile of 1.0 $\mu\text{g/L}$ and 3.6 $\mu\text{g/L}$. For systems serving greater than 10,000, DBCM was not detected in single samples taken at the plant and from the distribution system based on a detection limit of 0.2 $\mu\text{g/L}$ (TSD, 1992).

Regional/Local Studies

Fair et al. (1988) analyzed drinking water from three community water supplies for chlorination by-products. DBCM concentrations reported for each of the plants ranged from <0.5-19 $\mu\text{g/L}$ in finished water at the plant and from <0.5-23 $\mu\text{g/L}$ in the distribution systems.

The EPA's five-year Total Exposure Assessment Methodology (TEAM) study measured the personal exposures of urban populations to a number of organic chemicals in air and drinking water in several U.S. cities. As part of the study, running tap water samples were collected from residences of nearly 850 study participants during the morning and the evening and analyzed for

DBCM content. Exhibit 4.3 shows DBCM concentrations found in drinking water from the five cities surveyed.

Exhibit 4.3 DBCM in Tap Water from the EPA TEAM study ($\mu\text{g/L}$)					
Location	Date Sampled	Sample Size	Mean	Median	Maximum
Elizabeth/Bayonne, New Jersey	Fall 1981	355	2.4		8.4
	Summer 1982	157	2.1		7.2
	Winter 1983	49	1.4		3
Los Angeles, CA	Winter 1984	117	9.4	11	
	Summer 1984	52	28	32	
Antioch/Pittsburg, California	Spring 1984	71	8	6.4	
Devils Lake, North Dakota	Fall 1982	24	0.09		0.45
Greensboro, North Carolina	Fall 1982	24	1.2		1.9

Sources: Hartwell, et al., 1987
Wallace et al., 1988
Wallace et al., 1987

Furlong and Ditri (1986 in Howard, 1990) detected DBCM in drinking water of 30 of 40 Michigan water treatment plants at a median concentration of $2.2 \mu\text{g/L}$.

Non-Drinking Water

Two surveys were found which analyzed groundwater for DBCM. The Arizona Department of Environmental Quality conducted a random survey of Arizona community water supply wells as part of an effort to determine the baseline water quality of its groundwater supplies. A total of 40 wells from 38 systems, serving 1,000 or more people, were sampled from July to September 1986, with 16 of the wells resampled in January of 1987. DBCM concentrations were measured at a maximum concentration of $1.9 \mu\text{g/L}$ (Ellingson and Redding, 1988). Fusillo et al. (1985 in Howard, 1990) analyzed 315 wells in the Potomac-Raritan-Magothy aquifer, adjacent to the Delaware River, for organic chemicals. DBCM was one of 27 organic chemicals identified.

Several studies were found which analyzed surface waters for DBCM. The Ohio River Valley Water Sanitation Commission (1982 in Howard, 1990) collected samples from 11 stations

along the Ohio River Basin from 1980 to 1981. DBCM was detected in 9.8% of the 4,972 samples analyzed, with most concentrations found between 0.1-1.0 $\mu\text{g/L}$. In 1981, DBCM was found at levels ranging from trace-0.015 $\mu\text{g/L}$ and not detected-0.63 $\mu\text{g/L}$ at 16 stations on the Niagara River and 95 stations on Lake Ontario, respectively (Kaiser et al., 1983 in Howard, 1990).

4.8 Bromoform

Bromoform or tribromomethane is a nonflammable, colorless, heavy liquid with a sweet chloroform like odor. The compound is reasonably stable toward chemical reactions under most environmental conditions. Bromoform is used as a chemical intermediate in organic synthesis; a solvent for waxes, greases, and soil; and an ingredient in fire-resistant chemicals. As a pharmaceutical, it is used as a sedative and antitussive and as a heavy-dense liquid, it is used as a gauge-fluid and in solid separations. Due to its relatively high vapor pressure (5.6 mm Hg at 25 °C) and its moderate solubility in water (3.2 gm/L at 30 °C), bromoform is expected to be lost from rivers and streams primarily through volatilization. In a model river 1 m deep, flowing at 1 m/sec, and with a wind velocity of 3 m/sec, the volatilization half-life was calculated to be 6.7 hours. Hydrolysis is not an important fate process for bromoform based on a hydrolysis rate of $3.2 \times 10^{11} \text{ sec}^{-1}$ (25°C and pH 7) which corresponds to a half-life of 686 years. Its Koc values of 282 and 100 indicate that bromoform should not sorb significantly onto sediments and soils. It is expected to be highly mobile in soil; therefore, leaching to groundwater may occur. Laboratory screening tests suggests biodegradation of bromoform in water may be a significant removal process (USEPA, 1989).

Bromoform occurs in public water supplies that chlorinate drinking water containing humic and fulvic acids and bromine that can enter source waters through natural and anthropogenic means. Bromide enters source water from its presence in geological formations and from saltwater intrusion. In addition, bromide enters the environment from the agricultural use of methyl bromide and the presence of ethylene dibromide in leaded gasoline. Several water quality factors affect the formation of bromoform including Total Organic Carbon (TOC), pH, and temperature. Surface water systems are expected to have higher frequencies of occurrence and higher concentrations of trihalomethanes than ground water systems due to the presence of organic material; however, the levels of bromoform in ground water supplies are found to be the same or higher than the levels in surface water supplies due to the higher occurrence of bromide in ground water sources. Since chlorine is used as a residual in water distribution systems for disinfection purposes, the formation of bromoform continues throughout the distribution systems (Stevens and Symons, 1977; Cooper et al., 1985).

Different treatment practices affect the formation of bromoform. The levels of bromoform can be reduced, though not eliminated, when chloramines are used to disinfect. The reduction is less, however, when chloramination involves a pre-chlorination step where a free chlorine residual is maintained through a portion of the water treatment process prior to the addition of ammonia. Preozonation followed by chloramines substantially reduces the formation of bromoform, but ozonation prior to chlorination may increase the formation of bromoform. Also,

the use of chlorine dioxide is expected to produce lower levels of bromoform than chlorine (Cooper et al., 1985).

According to the EPA's Toxic Release Inventory, the total release of bromoform to environmental media, due to manufacturing in 1988, was 8,600 lbs through surface water discharges alone (USEPA, 1990).

Drinking Water

National Studies

Bromoform occurrence in United States drinking water was described in eight surveys. In 1975, the National Organics Reconnaissance Survey (NORS), conducted by the EPA, collected drinking water samples from 80 cities nationwide. The survey sampled for several organics including trihalomethanes at the water treatment facilities. The median concentration for bromoform was below the detection limit of approximately 5 $\mu\text{g/L}$. The maximum level found was 92 $\mu\text{g/L}$. NORS was performed prior to the Total Trihalomethane regulation; therefore, these results may be higher than current levels (Symons et al., 1975).

The National Organics Monitoring Survey (NOMS) was conducted by the EPA from March 1976 to January 1977. In NOMS, 113 community water supplies were sampled during three phases. Surface water was the major source for 92 of the systems and ground water was the major source for the remaining 21 systems. Two analytical methods were employed that measured the bromoform concentrations at the time of sampling and measured the maximum bromoform concentrations due to the reaction of all the chlorine residual. The median concentrations of the three phases all ranged below the detection limit of 0.3 $\mu\text{g/L}$. The maximum value found was 280 $\mu\text{g/L}$. NOMS was conducted before the enactment of the Total Trihalomethane regulation; therefore, these results may be higher than current levels (Bull and Kopfler, 1990).

The Community Water Supply Survey (CWSS) was conducted by the EPA in 1978. The survey examined over 1,100 samples representing over 450 water supply systems. The samples were taken at the treatment plants and in the distribution systems. In the CWSS, 13% of the surface water supplies and 26% of the ground water supplies were positive for bromoform. For surface water supplies the mean of the positives and the overall median were 2.1 $\mu\text{g/L}$ and <1.0 $\mu\text{g/L}$, respectively. The mean of the positives, for ground water supplies, was 11 $\mu\text{g/L}$ and the overall median was below the minimum reporting limit of 0.5 $\mu\text{g/L}$ (Brass et al., 1981).

The Rural Water Survey (RWS) was conducted between 1978 and 1980, by the EPA, to evaluate the status of drinking water in rural America. Samples from over 2,000 households, representing more than 600 rural water supply systems, were examined. In the RWS, 18% of the surface water supplies and 12% of the ground water supplies were positive for bromoform. For the surface water supplies the mean of the positives and the overall median concentrations were 8.7 $\mu\text{g/L}$ and <0.5 $\mu\text{g/L}$, respectively. For the ground water supplies the mean of the

positives was 12 $\mu\text{g/L}$ and the overall median was below the minimum reporting limit of 0.5 $\mu\text{g/L}$ (Brass, 1981).

The Ground Water Supply Survey (GWSS) was conducted from December 1980 to December 1981, by the EPA, to develop data on the occurrence of volatile organic chemicals in ground water supplies. Out of a total of 945 ground water systems, 466 systems were chosen at random, while the remaining 479 systems were chosen on the basis of location near industrial, commercial, and waste disposal activities. Samples were collected at or near the entry to the distribution system. For bromoform, the median of the positives for the randomly chosen systems serving above and below 10,000 people were 2.4 $\mu\text{g/L}$ and 3.8 $\mu\text{g/L}$ with the occurrence rates of 15.7% and 30.6%, respectively. The non-randomly chosen systems had a median of the positives of 4.2 $\mu\text{g/L}$ and an occurrence rate of 30.9%. The maximum values for systems, random and non-random, serving above and below 10,000 were 68 $\mu\text{g/L}$ and 110 $\mu\text{g/L}$, respectively. The 90th percentile for DBCM in systems serving less than 10,000 people was 4.1 $\mu\text{g/L}$ and in systems serving greater than 10,000 it was 8.3 $\mu\text{g/L}$ (Westrick et al., 1983).

The Technical Support Division (TSD) of the Office of Ground Water and Drinking Water (OGWDW) maintains an unregulated contaminant database. For bromoform, the database contains 1,409 samples from nineteen states at the treatment facilities between 1984 and 1991. The mean and median concentrations were determined to be 2.5 $\mu\text{g/L}$ and 1 $\mu\text{g/L}$, respectively (TSD, 1991).

Case studies of 35 water utilities nationwide, of which 10 were located in California, sampled for bromoform in the clearwell effluent. Samples were taken for four quarters (spring, summer, and fall in 1988 and winter in 1989). The median for all four quarters was 0.57 $\mu\text{g/L}$, with the medians of the individual quarters ranging from 0.33-0.88 $\mu\text{g/L}$. The maximum value found was 72 $\mu\text{g/L}$. For all four quarters, 75% of the data was below 2.8 $\mu\text{g/L}$ (Krasner et al., 1989b; USEPA and AMWA, 1989).

The EPA's Technical Support Division (TSD) has compiled a database on data from its disinfection by-products field studies. The studies included a chlorination by-products survey, conducted from October 1987 to March 1989. In this survey, bromoform was sampled for in finished water at the treatment plant and in the distribution system. For surface water systems, the mean concentration in finished water for systems serving above and below 10,000 people was 0.7 $\mu\text{g/L}$ and 0.9 $\mu\text{g/L}$, with the 90th percentile of 1.5 $\mu\text{g/L}$ and 4.9 $\mu\text{g/L}$ for 42 samples and 20 samples, respectively. In the distribution system, the mean was 0.8 $\mu\text{g/L}$ and 1.4 $\mu\text{g/L}$ for plants serving above and below 10,000, with the 90th percentile concentration of 3.1 $\mu\text{g/L}$ and 5.1 $\mu\text{g/L}$ for 39 samples and 11 samples, respectively. The ground water systems serving less than 10,000 had a mean bromoform concentration in finished water samples and distribution system samples, respectively, of 0.6 $\mu\text{g/L}$ and 2.3 $\mu\text{g/L}$ for 7 observations and 5 observations, with the 90th percentile of 2.6 $\mu\text{g/L}$ and 10.0 $\mu\text{g/L}$. For systems serving greater than 10,000, bromoform was not detected in single samples taken at the plant and from the distribution system based on a detection limit of 0.2 $\mu\text{g/L}$ (TSD, 1992).

Regional/Local Studies

The EPA's five-year Total Exposure Assessment Methodology (TEAM) study measured the personal exposures of urban populations to a number of organic chemicals in air and drinking water in several U.S. cities. As part of the study, drinking water samples from the homes of 188 individuals chosen from Los Angeles and the Antioch/Pittsburg, California areas were sampled for bromoform in 1984. Running tap water samples were collected in the homes of each individual in the morning and the evening of the study day. In Los Angeles, 117 residences were sampled in the winter. Bromoform was found at a mean level of 0.08 $\mu\text{g/L}$ and a median of 0.54 $\mu\text{g/L}$. In the summer, the mean and median for samples from 52 residences was 8 $\mu\text{g/L}$ and 3.0 $\mu\text{g/L}$. In Antioch, samples were collected from 71 residences, with a mean of 0.8 $\mu\text{g/L}$ and a median of 0.58 $\mu\text{g/L}$ (Hartwell, et al., 1987 and Wallace et al., 1988).

The EPA's Region V Organics survey sampled finished water from 83 sites. Bromoform was found at a median concentration of 1 $\mu\text{g/L}$ and a maximum level of 7 $\mu\text{g/L}$. A total of 14% of the locations sampled contained detectable levels of bromoform (USEPA, 1980a in USEPA, 1989). Furlong and Ditri (1986 in USEPA, 1989) reported that a survey of 40 plants in Michigan had a median bromoform concentration of 0.1 $\mu\text{g/L}$, with a 7.5% detection rate. Kelley (1985 in USEPA, 1989) sampled 18 drinking water plants in Iowa. Bromoform was detected in 50% of the samples with a range of 1.0-10 $\mu\text{g/L}$. Fair et al. (1988) analyzed drinking water from three community water supplies for chlorination by-products. Bromoform concentrations reported for each of the plants ranged from <0.5-2.5 $\mu\text{g/L}$ in finished water at the plants and from <0.5-3.1 $\mu\text{g/L}$ in the distribution systems.

Non-Drinking Water

The EPA's 1975 National Organic Reconnaissance Survey (NORS), sampled raw water sources of 80 U.S. water supplies. Of these 80 supplies, 16 had ground water sources and 64 had surface water sources. Based on the survey's results, bromoform was detected in raw water samples from 2 systems at concentrations of 0.2 and 0.3 $\mu\text{g/L}$. The detection limit varied from 0.1-0.4 $\mu\text{g/L}$ (Symons et al., 1975).

Three additional surveys were found which analyzed groundwater for bromoform. The largest of these surveys collected groundwater samples from sites New Jersey from 1977 to 1979. Out of 1,072 samples tested, 22% were positive for bromoform (Page, 1981 in USEPA, 1989). Concentrations ranged from the minimum reportable concentration of 0.1-34.7 $\mu\text{g/L}$ (Burmester, 1982 in USEPA, 1989). The Arizona Department of Environmental Quality conducted a random survey of Arizona community water supply wells as part of an effort to determine the baseline water quality of its groundwater supplies. A total of 40 wells from 38 systems, serving 1,000 or more people, were sampled from July to September 1986, with 16 of the wells resampled in January 1987. Bromoform concentrations were measured at a maximum concentration of 5.4 $\mu\text{g/L}$ (Ellingson and Redding, 1988). Rao et al. (1985 in USEPA, 1989) reported that bromoform was detected in groundwater from Delaware at a concentration of 20 $\mu\text{g/L}$.

A total of six studies were found which analyzed only surface waters for bromoform. In a survey of surface waters located near industrial sites, a total of 204 water samples were analyzed. Bromoform was detected in 3% of the samples (Helz, 1980 in USEPA, 1989). In a survey of surface waters in New Jersey, 604 samples were collected from 1977 to 1979. Bromoform was detected at 32.6% of the sites sampled, with a maximum reported concentration of 3.7 $\mu\text{g/L}$ (Page, 1981 in USEPA, 1989). Veenstra and Schnoor (1980 in USEPA, 1989) reported that bromoform levels in the Iowa River from October 1977 through October 1978 ranged from <0.5-6 $\mu\text{g/L}$, with an average concentration of 1.7 $\mu\text{g/L}$. The detection limit was 0.5 $\mu\text{g/L}$. In 1981, 17 stations along the lower Niagara River detected bromoform in 35.3% of water samples analyzed, with levels ranging from trace-6 ng/L (Kaiser et al., 1983 in USEPA, 1989). Bromoform was detected in 12.2% of water sampled from Lake Ontario in 1981. Concentrations ranged from trace-0.007 $\mu\text{g/L}$ (Kaiser et al., 1983 in USEPA, 1989). DeWalle and Chian (1978 in USEPA, 1989) found bromoform in 7% of 30 water samples collected from the Delaware river basin in February, 1976.

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