

Occurrence Assessment for the Final Stage 2 Disinfectants and Disinfection Byproducts Rule

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Acronyms

AUX1	Auxiliary Database 1
AUX2	Auxiliary Database 2
AUX3	Auxiliary Database 3
AUX4	Auxiliary Database 4
AUX5	Auxiliary Database 5
AUX6	Auxiliary Database 6
AUX8	Auxiliary Database 8
AVG1	Average 1 Distribution System Sampling Location
AVG2	Average 2 Distribution System Sampling Location
BAT	Best Available Technology
BCAA	Bromochloracetic Acid
BCAN	Bromochloroacetonitrile
BDCAA	Bromodichloroacetic Acid
BDCM	Bromodichloromethane
BDI	Below Detection Limit
	Carbon
	Calour Cathonata
CDDAA	Chlorodibromosostia Asid
CUBAA	Chlorol Heidrate
CH	Chiorai Hydrate
CHBr ₃	Bromotorm
CHCl ₃	Chloroform
CI	Chloride
Cl ₂	Chlorine
$Cl_2:NH_3-N$	Chlorine to Ammonia Nitrogen ratio
Cl ₃	Trichloride
	Chlorine Dioxide
ClO_2	Chlorite
ClO_3^-	Chlorate
CNCl	Cyanogen Chloride
СР	Chloropicrin
CT	Disinfectant Residual Concentration*Contact Time
CWS	Community Water System
CWSS	Community Water System Survey
DBAA	Dibromoacetic Acid
DBAN	Dibromoacetonitrile
DBCM	Dibromochloormethane
DBP	Disinfection Byproducts
DBPR	Disinfectants/Disinfection Byproducts Rule
DCAA	Dichloroacetic Acid
DCAN	Dichloroacetonitrile
DCP	Dichloropropanone
DS	Distribution System
DSE	Distribution System Equivalent
EPA	U.S. Environmental Protection Agency
ESWTR	Enhanced Surface Water Treatment Rule
FACA	Federal Advisory Committee Act
FBRR	Filter Backwash Recycling Rule
FR	Federal Register

GWSS	Ground Water Supply Survey
GWUDI	Ground Water Under the Direct Influence of Surface Water
HAA	Haloacetic Acid
HAA5	Haloacetic Acid-Five
HAA6	Haloacetic Acid-Six
HAA9	Haloacetic Acid-Nine
HAN	Haloacetonitrile
HAN4	Haloacetonitriles-Four
HC1	Hydrochloric Acid
HOCI	Hypochlorous Acid
ICR	Information Collection Rule
ICREED	Information Collection Rule Federal Database System
ICRSS	Information Collection Rule Supplemental Surveys
IDSE	Initial Distribution System Evaluation
IESWTR	Interim Enhanced Surface Water Treatment Rule
kg	Kilogram
кg I	Liter
	Litti Locational Punning Annual Avarage
	Long Term 1 Enhanced Surface Water Treatment Bule
LILESWIK	Long Term 2 Enhanced Surface Water Treatment Dula
LIZESWIK M DDD	Long Term 2 Enhanced Surface water Treatment Rule
MDAA	Microbial and Disinfection Byproduct
MBAA	Monobromoacetic Acid
MCAA	Monochloroacetic Acid
MCLG	Maximum Contaminant Level Goal
MCL	Maximum Contaminant Level
MDL	Method Detection Limit
mg	Milligram
μg	Microgram
MRDL	Maximum Residual Disinfectant Level
MRDLG	Maximum Residual Disinfectant Level Goal
MRL	Minimum Reporting Level
Ν	Nitrogen
Na	Sodium
NH ₃	Ammonia
NODA	Notice of Data Availability
NOM	Natural Organic Matter
NPDWR	National Primary Drinking Water Regulation
NRWA	National Rural Water Association
NTNCWS	Nontransient Noncommunity Water System
NTU	Nephelometric Turbidity Units
O ₂	Oxygen
$O_{3(aq)}$	Aqueous Ozone
OCl ⁻	Hypochlorite Ion
OGWDW	Office of Ground Water and Drinking Water
PAC	Powdered Activated Carbon
ppb	Parts per billion
ppm	Parts per million
PWS	Public Water System
RPD	Relative Percent Difference
OA/OC	Quality Assurance and Quality Control
RAA	Running Annual Average
SDS	Simulated Distribution System
~ ~ ~	

SQLStructured Query LanguageSUVASpecific UV AbsorbanceSWATSurface Water Analytical ToolSWTRSurface Water Treatment RuleTBAATribromoacetic AcidTCAATrichloroacetic AcidTCRTotal Coliform RuleTCPTrichloropropanoneTHMTrihalomethanesTOCTotal Organic CarbonTOXTotal Organic HalidesTTHMTotal TrihalomethanesTWGTechnical Working GroupUVUltraviolet RadiationVOCVolatile Organic CompoundWTPWater Treatment Plant	SDWA	Safe Drinking Water Act
SUVASpecific UV AbsorbanceSWATSurface Water Analytical ToolSWTRSurface Water Treatment RuleTBAATribromoacetic AcidTCAATrichloroacetic AcidTCANTrichloroacetonitrileTCRTotal Coliform RuleTCPTrichloropropanoneTHMTrihalomethanesTNCWSTransient Noncommunity Water SystemTOCTotal Organic CarbonTOXTotal Organic HalidesTTHMTotal TrihalomethanesTWGTechnical Working GroupUVUltraviolet RadiationVOCVolatile Organic CompoundWTPWater Treatment Plant	SQL	Structured Query Language
SWATSurface Water Analytical ToolSWTRSurface Water Treatment RuleTBAATribromoacetic AcidTCAATrichloroacetic AcidTCANTrichloroacetonitrileTCRTotal Coliform RuleTCPTrichloropropanoneTHMTrihalomethanesTNCWSTransient Noncommunity Water SystemTOCTotal Organic CarbonTOXTotal Organic HalidesTTHMTotal TrihalomethanesTWGTechnical Working GroupUVUltraviolet RadiationVOCVolatile Organic CompoundWTPWater Treatment Plant	SUVA	Specific UV Absorbance
SWTRSurface Water Treatment RuleTBAATribromoacetic AcidTCAATrichloroacetic AcidTCANTrichloroacetonitrileTCRTotal Coliform RuleTCPTrichloropropanoneTHMTrihalomethanesTNCWSTransient Noncommunity Water SystemTOCTotal Organic CarbonTOXTotal Organic HalidesTTHMTotal TrihalomethanesTWGTechnical Working GroupUVUltraviolet RadiationVOCVolatile Organic CompoundWTPWater Treatment Plant	SWAT	Surface Water Analytical Tool
TBAATribromoacetic AcidTCAATrichloroacetic AcidTCANTrichloroacetonitrileTCRTotal Coliform RuleTCPTrichloropropanoneTHMTrihalomethanesTNCWSTransient Noncommunity Water SystemTOCTotal Organic CarbonTOXTotal Organic HalidesTTHMTotal TrihalomethanesTWGTechnical Working GroupUVUltraviolet RadiationVOCVolatile Organic CompoundWTPWater Treatment Plant	SWTR	Surface Water Treatment Rule
TCAATrichloroacetic AcidTCANTrichloroacetonitrileTCRTotal Coliform RuleTCPTrichloropropanoneTHMTrihalomethanesTNCWSTransient Noncommunity Water SystemTOCTotal Organic CarbonTOXTotal Organic HalidesTTHMTotal TrihalomethanesWGTechnical Working GroupUVUltraviolet RadiationVOCVolatile Organic CompoundWTPWater Treatment Plant	TBAA	Tribromoacetic Acid
TCANTrichloroacetonitrileTCRTotal Coliform RuleTCPTrichloropropanoneTHMTrihalomethanesTNCWSTransient Noncommunity Water SystemTOCTotal Organic CarbonTOXTotal Organic HalidesTTHMTotal TrihalomethanesTWGTechnical Working GroupUVUltraviolet RadiationVOCVolatile Organic CompoundWTPWater Treatment Plant	TCAA	Trichloroacetic Acid
TCRTotal Coliform RuleTCPTrichloropropanoneTHMTrihalomethanesTNCWSTransient Noncommunity Water SystemTOCTotal Organic CarbonTOXTotal Organic HalidesTTHMTotal TrihalomethanesTWGTechnical Working GroupUVUltraviolet RadiationVOCVolatile Organic CompoundWTPWater Treatment Plant	TCAN	Trichloroacetonitrile
TCPTrichloropropanoneTHMTrihalomethanesTNCWSTransient Noncommunity Water SystemTOCTotal Organic CarbonTOXTotal Organic HalidesTTHMTotal TrihalomethanesTWGTechnical Working GroupUVUltraviolet RadiationVOCVolatile Organic CompoundWTPWater Treatment Plant	TCR	Total Coliform Rule
THMTrihalomethanesTNCWSTransient Noncommunity Water SystemTOCTotal Organic CarbonTOXTotal Organic HalidesTTHMTotal TrihalomethanesTWGTechnical Working GroupUVUltraviolet RadiationVOCVolatile Organic CompoundWTPWater Treatment Plant	TCP	Trichloropropanone
TNCWSTransient Noncommunity Water SystemTOCTotal Organic CarbonTOXTotal Organic HalidesTTHMTotal TrihalomethanesTWGTechnical Working GroupUVUltraviolet RadiationVOCVolatile Organic CompoundWTPWater Treatment Plant	THM	Trihalomethanes
TOCTotal Organic CarbonTOXTotal Organic HalidesTTHMTotal TrihalomethanesTWGTechnical Working GroupUVUltraviolet RadiationVOCVolatile Organic CompoundWTPWater Treatment Plant	TNCWS	Transient Noncommunity Water System
TOXTotal Organic HalidesTTHMTotal TrihalomethanesTWGTechnical Working GroupUVUltraviolet RadiationVOCVolatile Organic CompoundWTPWater Treatment Plant	TOC	Total Organic Carbon
TTHMTotal TrihalomethanesTWGTechnical Working GroupUVUltraviolet RadiationVOCVolatile Organic CompoundWTPWater Treatment Plant	TOX	Total Organic Halides
TWGTechnical Working GroupUVUltraviolet RadiationVOCVolatile Organic CompoundWTPWater Treatment Plant	TTHM	Total Trihalomethanes
UVUltraviolet RadiationVOCVolatile Organic CompoundWTPWater Treatment Plant	TWG	Technical Working Group
VOCVolatile Organic CompoundWTPWater Treatment Plant	UV	Ultraviolet Radiation
WTP Water Treatment Plant	VOC	Volatile Organic Compound
	WTP	Water Treatment Plant

1. Introduction

The United States Environmental Protection Agency (EPA) Office of Ground Water and Drinking Water (OGWDW) is developing interrelated drinking water regulations to control microbial pathogens, residual disinfectants, and disinfection byproducts in drinking water. These rules are required by the Safe Drinking Water Act (SDWA) Amendments of 1996 and are collectively known as the microbial and disinfection byproducts (M-DBP) rules.

The Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 DBPR) and the Interim Enhanced Surface Water Treatment Rule (IESWTR), the first set of M-DBP rules under the SDWA Amendments, were promulgated in December 1998. The Stage 1 DBPR and the IESWTR were the culmination of a 6-year rule development process that included regulatory negotiations with representatives of the water industry, environmental and public health groups, and local, State¹, and Federal government agencies.

To support rule development, EPA expanded its microbial and disinfection byproduct (DBP) research program and entered into collaborative efforts with other agencies and the water industry to collect data. This data collection effort included the Information Collection Rule (ICR) and the ICR Supplemental Survey (ICRSS). In addition, under a joint effort between EPA and the National Rural Water Association (NRWA), NRWA State chapters conducted a survey of disinfection byproduct and treatment information at small public water systems (PWSs)².

EPA has worked with stakeholders under the Federal Advisory Committee Act (FACA) to develop the proposed Stage 2 Disinfection Byproducts Rule (Stage 2 DBPR) and Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). These rules have been developed concurrently, using occurrence data from the ICR and other available sources to ensure that microbial protection is maintained or enhanced while exposure to DBPs is reduced.

This occurrence assessment supports the Stage 2 DBPR. The document has been revised since the proposal to reflect both public and peer review comments, as well as to maintain consistency with the Stage 2 Economic Analysis (USEPA 2005a). The remainder of this chapter is organized as follows:

- Section 1.1 summarizes the purpose of this document.
- Section 1.2 describes the history of drinking water regulations leading up to the Stage 2 DBPR.
- Section 1.3 provides a brief synopsis of the factors affecting DBP formation.
- Section 1.4 describes the main data source, the ICR.

¹For the purposes of this document, "States" are defined as States or territories with primacy or other primacy agencies.

²PWSs are systems that provide water for human consumption through pipes or other constructed conveyances and that have at least 15 service connections or regularly serve an average of at least 25 individuals per day for at least 60 days per year.

- Section 1.5 describes other sources used.
- Section 1.6 describes the rest of the chapters and appendices that make up this document.

1.1 Purpose of the Occurrence Document

This document serves two main purposes. First, it presents new data and analyses as an addendum to the *Occurrence Assessment for Disinfectants/Disinfection Byproducts in Public Drinking Water Supplies* document (USEPA 1998c), which supported the Stage 1 DBPR. In order to update the 1998 document to support the current rulemaking, EPA conducted additional information searches to identify articles and studies from the scientific literature and from recent conferences in the relevant subject areas. EPA also used the results of the ICR data collection effort, which was the primary source of the new DBP occurrence data. Analyses of this new DBP information and ICR data have been incorporated into the document.

The second purpose of the document is to evaluate DBP occurrence to characterize the post-Stage 1 baseline occurrence conditions. Because the compliance deadline for the Stage 1 DBPR was relatively recent (January 2002 for medium and large surface water systems and January 2004 for ground water and small surface water systems), all observed data in this document represent pre-Stage 1 conditions (i.e., conditions before the implementation of the Stage 1 DBPR). Chapter 4 of this occurrence document provides one possible analysis of DBP formation and occurrence for post-Stage 1 DBPR conditions.

To provide support to the Stage 2 DBPR rulemaking, this document focuses on analyses of the following data:

- Disinfectant use and residual concentrations.
- DBP precursors and other water quality parameters affecting DBP formation.
- Occurrence of regulated DBPs
 - Total Trihalomethanes (TTHM)
 - Haloacetic Acid-Five (HAA5)
 - Bromate
 - Chlorite

Analyses of TTHM and HAA5 occurrence focus on the distribution system. Spatial and temporal variability of TTHM and HAA5 occurrence in the distribution system is evaluated for the post-Stage 1 DBPR baseline in Chapter 4. Speciation of TTHM and HAA5 are contained in Appendix A. The ICR also contains other, non-regulated DBP data that is briefly summarized in section 3.1.3.1. Alternative and additional analyses are presented in the *Information Collection Rule Data Analysis* document (McGuire et al. 2002) (this includes some analyses of water quality data collected under the ICR that are not relevant to the Stage 2 DBPR rulemaking).

1.2 Regulatory Background

1.2.1 Statutory Authority for Promulgating the Rule

The primary responsibility for regulating the quality of drinking water lies with EPA. The SDWA establishes this responsibility and defines the mechanisms at the Agency's disposal to protect public health. EPA sets standards by identifying which contaminants should be regulated and by establishing the maximum levels of the contaminants allowed in drinking water.

Section 1412(b)(1) of the 1996 SDWA reauthorization mandated new drinking water requirements. EPA's general authority to set Maximum Contaminant Level Goals (MCLGs) and develop the National Primary Drinking Water Regulations (NPDWRs) was modified to apply to contaminants that "may have an adverse effect on the health of persons," are "known to occur or there is a substantial likelihood that the contaminant will occur in public water systems with a frequency and at levels of public health concern," and for which, "in the sole judgment of the Administrator, regulation of such contaminant presents a meaningful opportunity for health risk reductions for persons served by public water systems" (SDWA 1412(b)(1)(A)).

To regulate a contaminant, EPA sets an MCLG at a level at which no known or anticipated adverse health effects occur. MCLGs are established solely on the basis of protecting public health and are not enforceable. EPA simultaneously sets an enforceable Maximum Contaminant Level (MCL) as close as technologically feasible to the MCLG, while taking costs into consideration. If it is not feasible to measure the contaminant at levels presumed to have impacts on health, a treatment technique can be specified in place of an MCL. For water systems, compliance with a drinking water regulation means either not exceeding the MCL or meeting treatment technology requirements.

Additionally, EPA identifies maximum concentrations of residual disinfectants that can occur in water without harming human health and sets Maximum Residual Disinfectant Level Goals (MRDLGs) and Maximum Residual Disinfectant Levels (MRDLs). PWSs maintain residual levels of disinfectants in the distribution system, following treatment, to ensure consumer protection from microbial contaminants. Like MCLGs, MRDLGs are not enforceable, while MRDLs are.

In addition to the general authorities cited above, SDWA 1412(b)(2)(C) requires specifically that EPA promulgate the Stage 2 DBPR.

The Administrator shall promulgate an Interim Enhanced Surface Water Treatment Rule, a Final Enhanced Surface Water Treatment Rule, a Stage 1 Disinfectants and Disinfection Byproducts Rule, and a Stage 2 Disinfectants and Disinfection Byproducts Rule in accordance with the schedule published in Volume 29, Federal Register, Page 6361 (February 10, 1994), in Table III.13 of the proposed Information Collection Rule. (SDWA 1412(b)(2)(C))

The following sections summarize the development of relevant NPDWRs over the past 20 years.

1.2.2 1979 Total Trihalomethane Rule

Under the Total Trihalomethane Rule (44 Federal Register (FR) 68624, November 29, 1979), EPA set an MCL for TTHM (the sum of the concentrations of chloroform, bromoform, bromodichloro-methane,

and dibromochloromethane) of 0.10 milligrams per liter (mg/L) as a running annual average (RAA) of quarterly measurements. This standard applied to CWSs using surface or ground water that served at least 10,000 people and that added a disinfectant to the drinking water during any part of the treatment process. This 1979 rule was superseded by the 1998 Stage 1 DBPR (section 1.2.9) with which all CWSs and NTNCWSs must have complied by January 2004.

1.2.3 1989 Total Coliform Rule

The Total Coliform Rule (TCR) (54 FR 27544, June 29, 1989) applies to all PWSs. Because monitoring PWSs for every possible pathogenic organism is not feasible, coliform organisms are used as indicators of possible contamination. Coliforms are easily detected in water and are used to indicate a system's vulnerability to pathogens. In the TCR, EPA set an MCLG of zero for total coliforms. EPA also set a monthly MCL for total coliforms and required testing of total-coliform-positive cultures for the presence of *E. coli* or fecal coliforms. *E.coli* and fecal coliforms indicate more immediate health risks from sewage or fecal contamination and are used as the indicator of an acute MCL violation. Coliform monitoring frequency is determined by population served, the type of system (community or noncommunity) and the type of source water (surface water or ground water). In addition, the TCR required sanitary surveys every 5 years (or 10 years for noncommunity systems using disinfected ground water) for systems that collect fewer than 5 routine total coliform samples per month (typically systems serving fewer than 4,100 people).

1.2.4 1989 Surface Water Treatment Rule

Under the Surface Water Treatment Rule (SWTR) (54 FR 27486, June 29, 1989), EPA set MCLGs of zero for *Giardia lamblia*, viruses, and *Legionella* and established requirements for all PWSs using surface water or GWUDI as a source. The SWTR includes treatment technique requirements for filtered and unfiltered systems that are intended to protect against the adverse health effects associated with *Giardia lamblia*, viruses, and *Legionella*, as well as many other pathogenic organisms. These requirements include:

- Maintenance of a disinfectant residual in water entering and within the distribution system.
- Removal or inactivation of at least 99.9 percent (3 logs) of *Giardia* and 99.99 percent (4 logs) of viruses.
- For filtered systems, meeting a turbidity performance standard for the combined filter effluent of 5 nephelometric turbidity units (NTUs) as a maximum and 0.5 NTU in 95 percent of monthly measurements, based on 4-hour monitoring for treatment plants using conventional treatment or direct filtration (with separate standards for other filtration technologies). These requirements were enhanced by the 1998 Interim Enhanced Surface Water Treatment Rule (IESWTR) and the 2002 Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR).
- Watershed control programs and other requirements for unfiltered systems.

1.2.5 1996 Information Collection Rule

The Information Collection Rule (ICR) (61 FR 24354, May 14, 1996) applied to PWSs serving more than 100,000 people. A more limited set of ICR requirements covered ground water systems serving 50,000 to 100,000 people.

The ICR authorized EPA to collect occurrence and treatment information from water treatment plants to help evaluate the possible need for changes to microbial requirements and microbial treatment practices and to help evaluate the need for future regulation of disinfectants and DBPs. The ICR provided EPA with information on the national occurrence of (1) chemical byproducts that form when disinfectants used for microbial control react with naturally occurring compounds and ions present in source water; and (2) disease-causing microorganisms including *Cryptosporidium*, *Giardia*, viruses, and coliform bacteria. The ICR also mandated the collection of data on how water systems currently treat for contaminants. The ICR monthly sampling data provided 18 months of information on the quality of the influent and treated water, including pH, alkalinity, turbidity, temperature, calcium, total hardness, total organic carbon, ultraviolet₂₅₄ (UV) absorbency, bromide, ammonia, and disinfectant residual. These data provide some indication of the "treatability" of the water, the occurrence of contaminants, and the potential for DBP formation. The data collected under the ICR are being analyzed to help develop the LT2ESWTR and Stage 2 DBPR. A detailed description of the ICR is provided in Section 1.4.

1.2.6 1998 Interim Enhanced Surface Water Treatment Rule

The IESWTR (63 FR 69478, December 16, 1998) enhances the 1989 SWTR. It applies to PWSs serving at least 10,000 people and using surface water or GWUDI as a source. These systems began compliance with the IESWTR in January 2002. The purpose of the IESWTR is to improve control of the protozoan *Cryptosporidium* and to address tradeoffs between the risks of microbial pathogens and those of DBPs. The requirements and guidelines include:

- An MCLG of zero for *Cryptosporidium*.
- Removal of 99 percent (2 logs) of *Cryptosporidium* for systems that use filters.
- For filtered systems, a turbidity performance standard for the combined filter effluent of 1 NTU as a maximum and 0.3 NTU as a minimum in 95 percent of monthly measurements, based on 4-hour monitoring for treatment plants using conventional treatment or direct filtration.
- Continuous monitoring of individual filter effluent in conventional and direct filtration plants and recording turbidity readings every 15 minutes when these filters are on-line.
- A disinfection benchmark to assess the level of microbial protection provided before facilities change their disinfection practices to meet the requirements of the Stage 1 DBPR.
- Inclusion of *Cryptosporidium* in the definition of GWUDI and in the watershed control requirements for unfiltered PWSs.

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• Covers for all new finished water storage facilities.

• A primacy provision that requires States to conduct sanitary surveys for all surface water systems, including those serving fewer than 10,000 people.

The IESWTR was promulgated concurrently with the Stage 1 DBPR so that systems could coordinate their response to the risks posed by DBPs and microbial pathogens.

1.2.7 1998 Stage 1 Disinfectants and Disinfection Byproducts Rule

The Stage 1 DBPR (63 FR 69390, December 16, 1998) applies to all CWSs and NTNCWSs that add a chemical disinfectant to their water. Certain requirements designed to provide protection against acute health effects from chlorine dioxide also apply to transient noncommunity water systems (TNCWSs). Compliance for surface water and GWUDI systems serving at least 10,000 people began in January 2002. Surface water and GWUDI systems serving fewer than 10,000 people and all ground water systems were required to comply by January 2004.

The Stage 1 DBPR sets MRDLGs for chlorine (4 mg/L as chlorine (Cl₂)), chloramines (4.0 mg/L as Cl₂), and chlorine dioxide (0.8 mg/L as ClO₂); and MCLGs for bromodichloromethane (0 mg/L), bromoform (0 mg/L), dibromochloromethane (0.06 mg/L), dichloroacetic acid (0 mg/L), trichloroacetic acid (0.3 mg/L), bromate (0 mg/L), and chlorite (0.8 mg/L). The rule sets MRDLs for chlorine (4.0 mg/L as Cl₂), chloramines (4.0 mg/L as Cl₂), and chlorine dioxide (0.8 mg/L as ClO₂); and MCLs for TTHM (0.080 mg/L), HAA5 (0.060 mg/L), bromate (0.010 mg/L), and chlorite (1.0 mg/L). The MRDLs and MCLs, except those for chlorite and chlorine dioxide, are calculated as RAAs. For conventional surface water and GWUDI systems, a treatment technique—enhanced coagulation/softening—is specified for the removal of DBP precursors.

As noted in section 1.2.8, the Stage 1 DBPR was promulgated concurrently with the IESWTR to coordinate the control of DBPs and microbial contaminants.

1.2.8 2000 Proposed Ground Water Rule

The proposed Ground Water Rule (65 FR 30194, May 10, 2000) addresses fecal contamination in ground water systems. It also builds on the TCR through provisions based on further evaluation of *E. coli* monitoring results measured under the TCR. Key components of the approach for protection of ground water included in the proposed rule are:

- Sanitary surveys for all ground water systems.
- Hydrogeologic sensitivity assessments to identify ground water wells that are susceptible to fecal contamination.
- Triggered source water monitoring for an indicator of fecal contamination for all systems that do not achieve 4-log treatment, and in addition, routine source water monitoring for an indicator of fecal contamination that have been determined to draw from sensitive ground water sources.

- Correction of significant deficiencies and fecal contamination by eliminating the source of contamination, correcting the deficiency, providing an alternative source of water, or providing inactivation and/or removal of 99.99 percent (4 logs) of viruses.
- Compliance monitoring to ensure that disinfection treatment is reliably operated when it is used.

1.2.9 2001 Arsenic Rule

The Arsenic Rule (66 FR 6976, January 22, 2001) increases the level of public health protection against exposure to arsenic in drinking water. The rule revises the MCL for arsenic in drinking water from 0.05 mg/L to 0.010 mg/L and sets an MCLG of 0 mg/L for all CWSs and NTNCWSs. Clarification on how compliance is demonstrated for many inorganic and organic contaminants in drinking water is also given. All existing CWSs and NTNCWSs must comply with the Arsenic Rule by January 23, 2006.

1.2.10 2001 Filter Backwash Recycling Rule

The Filter Backwash Recycling Rule (FBRR) (66 FR 31086, June 8, 2001) regulates systems that return filter backwash to the treatment process. The rule applies to surface water and GWUDI systems that use direct or conventional filtration and recycle spent filter backwash water, sludge thickener supernatant, or liquids from dewatering processes. The rule requires that these recycled liquids be returned to a location such that all steps of a system's conventional or direct filtration are employed. The rule also requires systems to notify the State that they practice recycling. Finally, systems must collect and maintain information for review by the State.

1.2.11 2002 Long Term 1 Enhanced Surface Water Treatment Rule

The LT1ESWTR (67 FR 1812, January 14, 2002) enhances the 1989 SWTR requirements for small systems. LT1ESWTR enhances control of *Cryptosporidium* and other disease-causing microbes for surface water and GWUDI systems that serve fewer than 10,000 people. Key provisions in the LT1ESWTR are very similar to those for the IESWTR, but provide additional flexibility for small systems.

1.2.12 2005 Long Term 2 Enhanced Surface Water Treatment Rule

Promulgated in concert with the Stage 2 DBPR, the LT2ESWTR strengthens control of *Cryptosporidium*, and applies to all PWSs that use surface water or GWUDI as a source. It incorporates system-specific treatment requirements based on a "Microbial Framework" approach that targets high-risk systems. This approach involves assigning systems to different categories (or "bins") based on the levels of *Cryptosporidium* found in the source water. Additional treatment requirements, if any, are linked to the level of *Cryptosporidium*. A system will choose technologies and management practices from a "toolbox" of options appropriate to its bin.

Medium and large systems (those serving at least 10,000 people) that filter will be required to conduct *Cryptosporidium* source water monitoring for 24 months to determine their bin classification. Small systems (those serving fewer than 10,000 people) that filter will monitor *E. coli* bacteria in their

source water biweekly for 12 months. Based on their *E. coli* results, they may be required to monitor *Cryptosporidium* as well.

In addition to requirements for filtered systems, the LT2ESWTR will require unfiltered systems to continue to meet the filtration avoidance criteria under the 1989 SWTR and provide inactivation at 4 logs (99.99 percent) for virus, 3 logs (99.9 percent) for *Giardia*, and 2 to 3 logs (99 to 99.9 percent) for *Cryptosporidium* (depending on results of *Cryptosporidium* monitoring of source water). Building on the SWTR requirements, inactivation requirements for unfiltered systems subject to the LT2ESWTR must be met using a minimum of two disinfectants.

Also, the LT2ESWTR will require systems with uncovered finished water reservoirs to cover the reservoirs or treat reservoir discharge to the distribution system to achieve 4-log virus inactivation, 3-log *Giardia* inactivation, and 2-log *Cryptosporidium* inactivation.

1.3 Factors Affecting DBP Formation

Organic DBPs (and oxidation byproducts) are formed by the reaction between organic substances and oxidizing agents that are added to water during treatment. In most water sources, natural organic matter (NOM) is the major constituent of organic substances and DBP precursors. Organic substances and DBP precursors in water also come from a variety of other sources, including stormwater and wastewater. NOM is typically measured as TOC and as such the two terms are used interchangeably in much of the discussion presented here. Major factors affecting the type and amount of DBPs formed include:

- Type, dose, and residual concentration of disinfectant.
- Contact time and mixing conditions between disinfectant (oxidant) and precursors.
- Concentration and characteristics of precursors, such as TOC.
- Water temperature.
- Water chemistry (including pH, bromide ion concentration, organic nitrogen concentration, and presence of other reducing agents such as iron and manganese).

A description of these factors follows.

1.3.1 Impact of Disinfection Method on Organic DBP Formation

Organic DBPs can be subdivided into halogenated and non-halogenated byproducts. Halogenated organic disinfection byproducts are formed when organic compounds in water react with free chlorine, free bromine, or free iodine. The formation reactions may take place in the treatment plant or the distribution system. Free chlorine can be introduced to water directly as a primary or secondary disinfectant, or as a byproduct in the manufacture of chlorine dioxide. In general, primary disinfection kills or inactivates pathogens in water at the water treatment plant. Secondary disinfection provides a residual as the water leaves the treatment plant to control microbiological growth in the distribution system. Reactions between NOM and chlorine lead to the formation of a variety of halogenated DBPs including THMs and HAAs.

Free chlorine and ozone oxidize bromide ion to hypobromite ion/hypobromous acid, which in turn can react with NOM to form brominated DBPs (e.g., bromoform). The presence of bromide affects both the formation rate and yield of DBPs. As the ratio of bromide to NOM increases, the percentage of brominated DBPs increases. For example, Krasner (1999) reported the rate of THM formation is higher in waters with increased concentrations of bromide. Brominated DBPs can also form by bromine substitution in the chlorinated byproducts, with hypobromous acid an effective substituting agent (Krasner 1999). The presence of OBr- in chlorine feedstocks may also contribute to formation of brominated DBPs.

Non-halogenated DBPs may form when precursors (NOMs) react with strong oxidants. For example, the reaction of organics with ozone and hydrogen peroxide results in the formation of aldehydes, aldo- and keto-acids, and organic acids (Singer 1999). Chlorine can also trigger the formation of some non-halogenated DBPs (Singer and Harrington 1993). Many of the non-halogenated DBPs, such as aldehydes, are biodegradable.

Studies have documented that chloramines produce significantly lower DBP levels than free chlorine, and there is no clear evidence that the reaction of NOM and chloramine leads to the formation of THMs (Singer and Reckhow 1999; USEPA 1999a). An empirical DBP formation model calibrated using ICR data predicted THM and HAA formation in full-scale plants and distribution systems under chloraminated conditions at fractions of the amount that would be expected based on observations of DBP formation under free chlorine conditions. The amount of DBP formation under chloraminated conditions varied from 5 percent to 35 percent of that calculated for free chlorine, depending on the individual DBP species (Swanson et al. 2001).

It is possible that DBPs might form during the mixing of chlorine and ammonia, when free chlorine might react with NOM before the complete formation of chloramines. In addition, monochloramine slowly hydrolyzes to release free chlorine in water. This free chlorine may contribute to the formation of small amounts of additional DBPs in the distribution system. Low DBP formation due to chloramines can be an acceptable alternative, especially at the farthest locations of the distribution system where high DBP formations could potentially occur in the presence of free chlorine residuals.

The use of chlorine dioxide as a disinfectant does not produce significant amounts of organic halogenated DBPs. Only small amounts of total organic halides (TOXs, the class of DBPs made up of halogenated organic by-products that include THMs and HAAs) are formed. However, sometimes excess chlorine is added to water to ensure complete reaction with sodium chlorite during the production of chlorine dioxide. This excess chlorine, in the presence of NOM, can cause THMs and HAAs to form.

To date, there is no evidence to suggest that use of UV as a disinfectant results in the formation of any disinfection byproducts; however, little research has been performed in this area. Most of the research regarding application of UV and DBP formation has focused on chlorinated DBP formation as a result of UV application prior to the addition of chlorine or chloramines. The evidence suggests UV does not promote chlorinated DBP formation.

Ozone does not produce chlorinated DBPs; however, ozone can alter the reactions between chlorine and NOM, and affect the speciation of chlorinated DBPs if chlorine is subsequently added downstream. In waters with sufficient bromide concentrations, ozonation can lead to the formation of bromate and other brominated DBPs. Bromate, like THMs and HAAs, is a regulated DBP. Ozonation of natural waters also produces aldehydes, haloketones, ketoacids, carboxylic acids, and other types of biodegradable organic material. The biodegradable fraction of organic material can serve as a nutrient source for microorganisms, and should be removed to prevent microbial regrowth in the distribution system. This is generally accomplished by allowing filters to run biologically, i.e., without a disinfectant residual present.

1.3.2 Disinfectant Dose

The concentration of disinfectant can affect the formation of DBPs. In general, changes in the disinfectant dose have a great impact on DBP formation during primary disinfection because the disinfectant is typically the limiting reactant in DBP formation reactions. The effect of disinfection dose on DBP formation is typically more significant in primary disinfection than in secondary disinfection During secondary disinfection, DBP formation reactions may be precursor-limited since an excess of disinfectant is added to the water. In the distribution system, DBP formation reactions become disinfectant-limited when the free chlorine residual drops to low levels. (Singer and Reckhow [1999] suggested a free chlorine residual concentration of 0.3 mg/L as a rule of thumb.)

In many systems, booster disinfection is applied to raise disinfectant residual concentration, especially in remote areas of the distribution system or near storage tanks where water age may be high and disinfectant residuals can be low. The additional chlorine dose applied to the water at these booster facilities can result in increased formation of THMs and HAAs. Further, booster chlorination (increasing chlorine concentrations in the distribution system) can maintain high HAA concentrations because the increased disinfection residuals can prevent the biodegradation of HAAs.

1.3.3 Contact Time and DBP Formation

DBPs continue to form in drinking water as long as disinfectant residuals and reactive DBP precursors are present. Generally, the longer the contact time between disinfectant/oxidant and NOM, the greater the amount of DBPs that can be formed. In the presence of a continuing significant disinfectant residual, both THMs and HAAs have generally high chemical stabilities and will persist after formation (Singer and Reckhow 1999).

However, there are some chemical stability differences between THMs and HAAs which can result in differences in long term accumulations. High TTHM values usually occur at points in the distribution system with the longest total residence time (the "oldest" water age). In contrast, high HAAs values cannot be consistently related to water age because HAAs are known to biodegrade over time when the disinfectant residual is low. This might result in relatively low HAA concentrations in areas of the distribution system where disinfectant residuals are depleted.

In contrast to these chlorination byproducts, ozonation byproducts form more rapidly. However, because residual ozone dissipates rapidly in water, there is a much shorter period during which ozone byproduct formation can occur compared to chlorination byproducts (Singer and Reckhow 1999). The rate of formation for both THMs and HAAs is relatively s1ow–on the order of days for ultimate formation. Bromate formation, however, is considerably faster–on the order of seconds.

1.3.4 Concentration and Characteristics of Precursors

In addition to disinfectant dose and contact time, the formation of halogenated DBPs is related to the concentration of NOM at the point of chlorination. Higher amounts of DBPs are formed in waters with higher concentrations of precursors. Studies conducted with different fractions of NOM have indicated the reaction between chlorine and NOM with high aromatic content tends to form higher DBP levels than NOM with low aromatic content (Singer and Reckhow 1999). For this reason, UV absorbance (typically indicated by UV absorbance at 254 nm $[UV_{254}]$), which is generally related to the aromatic and unsaturated

components of NOM, is considered a good predictor of the tendency of a source water to form THMs and HAAs (Owen et al. 1998; Singer and Reckhow 1999). The UV₂₅₄ measurement immediately upstream of the point(s) of chlorination within a treatment plant is, therefore, most directly related to THM and HAA formation potential. It should be noted that the more highly aromatic precursors, characterized by high UV_{254} in source waters, are more easily removed by coagulation.

1.3.5 Water Temperature

The rate of formation of THMs increases with increasing temperature. HAA formation rates may also increase with temperature, though the effects are less pronounced. Consequentially, the highest THM and HAA levels may occur in the warm summer months. However, water demands are often higher in warmer months, resulting in lower water age within the distribution system and helping to control DBP formation. Furthermore, high temperature conditions in the distribution system promote the accelerated depletion of residual chlorine, which can mitigate DBP formation and promote biodegradation of HAAs (unless chlorine dosages are increased to maintain high residuals) (Singer and Reckhow 1999). For these reasons, depending on system-specific conditions, the highest THM and HAA levels may be observed during months which are warm, but not necessarily the warmest.

Seasonal trends affect where high THM and HAA concentrations might be found. For example, when water is colder, microbial activity is typically lower and DBP formation kinetics are slower. Under these conditions, the highest THM and HAA concentrations might appear coincident with the oldest water in the system. In warmer water, the highest HAA concentrations might appear in fresher (younger) water, which is likely to contain higher disinfectant residuals that can prevent the biodegradation of HAAs.

1.3.6 Water pH

In the presence of NOM and chlorine, THM formation increases with increasing pH, whereas the formation of HAAs and other DBPs increase with decreasing pH. The increase of THMs at higher pH values is likely due to base catalyzed reactions that lead to THM formation. The HAA formation pathway can be altered at high pH since their precursors can hydrolyze (Singer and Reckhow 1999).

The major byproducts of ozonation are not affected by base hydrolysis. However, the rate of decomposition of ozone to hydroxyl radical is accelerated as pH increases. The increase in pH has been shown to result in a decrease in aldehydes, though there may be circumstances where the increased pH will lead to the formation of some carbonyl byproducts. More typically, low pH in ozone treated water has been shown to increase the formation of brominated DBP species. This is due to two factors. First, hypobromous acid and hypobromite are formed when ozone reacts with bromide water. Second, low pH shifts the equilibrium to hypobromous acid, which reacts with NOM to form brominated DBPs such as bromoform and dibromoacetic acid, but lowers the formation of hypobromite and subsequently bromate (Singer and Reckhow 1999).

1.4 The Primary Data Source: Information Collection Rule

The main source of occurrence data for large PWSs is the ICR. ICR monitoring requirements applied to surface and ground water CWSs serving at least 100,000 people, which included a total of 296 systems comprising 512 plants (which includes 11 plants with blended source water). The ICR generated data sets that characterize the water quality in each plant's source water, in several steps in the treatment

process, and at several points in the distribution system (reflecting finished water). The monitoring began in July 1997 and ended in December 1998.

This section describes the ICR data elements and other data requirements, ICR implementation activities, ICR sampling plans, data management activities, quality assurance activities, and the development of the auxiliary databases. The last two subsections (1.4.8 and 1.4.9) describe the methods used to analyze ICR data and how the data analyses are documented. Appendix C summarizes the uses of the ICR data and documents how data quality objectives are met. For more detailed information on the ICR data collection methodology and results, refer to the following publications:

- ICR Sampling Manual (USEPA 1996b)
- Information Collection Rule Data Analysis (McGuire et al. 2002)

1.4.1 Description of the ICR Data Set

ICR monitoring requirements depended on the system size and type. Surface water systems serving more than 100,000 people were required to monitor for DBPs and related parameters (e.g., DBP precursors, disinfectants), conduct microbial monitoring, collect treatment plant design and operating information, and monitor for treatment study applicability (which determined if a treatment study was required). Ground water systems serving more than 100,000 people were required to monitor for DBPs and related parameters and for treatment study applicability. Ground water systems serving more than 50,000 but fewer than 100,000 people were required to monitor only for treatment study applicability.

The following subsections describe ICR analytical requirements, sample locations, monitoring frequency, and minimum reporting levels. A summary of all requirements follows the discussion (Exhibit 1.1). For more detailed information, such as specific treatment sampling locations, refer to the *ICR Sampling Manual* (USEPA 1996b).

Analytical Requirements

Samples were analyzed for the following:

- Water quality parameters, including DBP precursors (temperature, pH, alkalinity, total organic carbon, etc.)
- **Disinfectants** (free chlorine residual, chloramine residual, etc.)
- **DBPs** (TTHM and individual THM species such as chloroform; HAA5, HAA6, HAA9, and individual HAA species; chlorite; bromate, etc.)

Since DBP formation depends on the type of disinfectant used, monitoring for each DBP did not occur at every plant. For example, chlorite is a byproduct primarily related to disinfection with chlorine dioxide and was therefore monitored only by plants that use chlorine dioxide.

Microbial analyses were also performed on some samples. Microbial results are not covered in this document; see the LT2ESWTR Occurrence Document (USEPA 2005b) for microbial regulations and results from the ICR.

Sample Locations

ICR samples were generally collected at the treatment plant influent, sites throughout the treatment plant (e.g., before and after filtration, before and after each point of disinfection), a finished water location (typically the same as the entry point sample except for plants that blend finished water from multiple treatment plants), and sites within the distribution system. A total of four distribution system monitoring locations were required for the ICR:

- Average Residence Time in the Distribution System (AVG1 and AVG2): two sample points in the distribution system, each representing an approximate average residence time, as designated by the water system.
- **Maximum Residence Time in the Distribution System (DS Maximum)**: a sample from the point in the distribution system that has the longest residence time, as designated by the water system.
- **Distribution System Equivalent (DSE)**: a sample from the point in the distribution system that has a well characterized detention time equivalent to a simulated distribution sample (SDS).

Plant characteristics, including source water and disinfectant type, determined the specific sampling location and frequency for certain parameters (see Exhibit 1.1).

Monitoring Frequency

General water quality parameters, DBP precursors, and disinfectant concentrations were monitored monthly, while most DBPs were monitored quarterly. Targeted DBP monitoring for bromate and chlorite was conducted monthly. Monthly samples were supposed to reflect typical operating conditions at the plant and each set was required to be collected within a 72-hour period. A minimum of 14 days was required between monthly sampling periods. A minimum of two months was required between quarterly sampling periods (USEPA 1996b).

Minimum Reporting Levels

The method detection limit (MDL) is defined as the minimum concentration of a substance that can be measured and reported with 99 percent confidence that the measured analyte concentration is greater than zero. Usually, measurements below the MDL concentration are considered qualitative, not quantitative, because they are not adequately precise to meet the needs of the data user(s). MDLs vary from laboratory to laboratory based on the method used, equipment, etc.

Because MDLs vary from method to method and from laboratory to laboratory, EPA established Minimum Reporting Levels (MRLs) for the ICR. MRLs were based on (1) a review of available occurrence data to confirm that most are above the MRL; (2) whether the concentration at the MRL could be measured taking use, burden, and status of analytical methods into consideration; and (3) recommendations of an expert panel. Although EPA recognizes that some laboratories could provide reliable data at concentrations below the MRL, a concentration measured below the MRL was not required to be reported; instead, "below the MRL" was reported. Exhibit 1.1 presents the ICR MRLs for water quality parameters, disinfectants, and DBPs. Section 1.4.8 explains how results that are "below the MRL" were handled in the ICR data analysis.

Analyte	Plant Types Required to Monitor	Sampling Locations (# of Sampling Locations) ¹	Frequency	Minimum Reporting Level (MRL)
Water Quality Parameters				
Total Organic Carbon (TOC)	All	Influent, Treatment, Finished	Monthly	0.7 mg/L as C
	All	Influent, Treatment, Finished	Monthly	
рН	All	Distribution System (4)	Quarterly	_
	Hypochlorite	Disinfectant Stock Solution	Quarterly	
Alkolinity ²	All	Influent, Treatment, Finished	Monthly	
	All	Distribution System (4)	Quarterly	-
Total Llardnapa ²	All	Influent, Treatment, Finished	Monthly	
Total Hardness -	All	Distribution System (4)	Quarterly	_
Turkidit 2	All	Influent, Treatment, Finished	Monthly	
Turbially -	All	Distribution System (4)	Quarterly	-
	All	Influent, Treatment, Finished	Monthly	
Temperature ²	All	Distribution System (4)	Quarterly	_
	Hypochlorite	Disinfectant Stock Solution	Quarterly	
Bromide	All	Influent, Treatment	Monthly	0.02 mg/L
UV ₂₅₄ absorbance	All	Influent, Treatment, Finished	Monthly	0.009 cm ⁻¹
Disinfectants	-			
	Free chlorine as residual	Treatment, Finished	Monthly	_
Free Chlorine Residual ²	disinfectant	Distribution System (4)	Quarterly	
	Hypochlorite	Disinfectant Stock Solution	Quarterly	
Total Chloring Residual ²	A 11	Treatment, Finished	Monthly	_
		Distribution System (4)	Quarterly	_
Chlorine Dioxide $(CIO_2)^2$	Chlorine Dioxide	Treatment, Finished, and Distribution System (3)	Monthly	-
Ozone ²	Ozone	Treatment	Monthly	_
DBPs	-			
Total Trihalomethanes (TTHM) ²	All	Treatment, Finished, and Distribution System (4)	Quarterly	-
Chloroform	All	Treatment, Finished, and Distribution System (4)	Quarterly	1.0 µg/L
Bromodichloromethane (BDCM)	All	Treatment, Finished, and Distribution System (4)	Quarterly	1.0 µg/L
Dibromochloromethane (DBCM)	All	Treatment, Finished, and Distribution System (4)	Quarterly	1.0 µg/L
Bromoform	All	Treatment, Finished, and Distribution System (4)	Quarterly	1.0 µg/L

Exhibit 1.1 ICR Plant Monitoring Requirements

Analyte	Plant Types Required to Monitor	Sampling Locations (# of Sampling Locations) ¹	Frequency	Minimum Reporting Level (MRL)
Haloacetic Acid-Five (HAA5) ²	All	Treatment, Finished, and Distribution System (4)	Quarterly	_
Haloacetic Acid-Six (HAA6) ²	All	Treatment, Finished, and Distribution System (4)	Quarterly	_
Haloacetic Acid-Nine (HAA9) ²	All Encouraged⁵	Treatment, Finished, and Distribution System (4)	Quarterly	_
Monochloroacetic Acid (MCAA)	All	Treatment, Finished, and Distribution System (4)	Quarterly	2.0 µg/L
Dichloroacetic Acid (DCAA)	All	Treatment, Finished, and Distribution System (4)	Quarterly	1.0 µg/L
Trichloroacetic Acid (TCAA)	All	Treatment, Finished, and Distribution System (4)	Quarterly	1.0 µg/L
Monobromoacetic Acid (MBAA)	All	Treatment, Finished, and Distribution System (4)	Quarterly	1.0 µg/L
Dibromoacetic Acid (DBAA)	All	Treatment, Finished, and Distribution System (4)	Quarterly	1.0 µg/L
Bromochloracetic acid (BCAA)	All	Treatment, Finished, and Distribution System (4)	Quarterly	1.0 µg/L
Bromodichloroacetic acid (BDCAA)	All Encouraged⁵	Treatment, Finished, and Distribution System (4)	Quarterly	1.0 µg/L
Chlorodibromoacetic acid (CDBAA)	All Encouraged⁵	Treatment, Finished, and Distribution System (4)	Quarterly	2.0 µg/L
Tribromoacetic acid (TBAA)	All Encouraged⁵	Treatment, Finished, and Distribution System (4)	Quarterly	4.0 µg/L
Bromate (low-level)	Chlorine Dioxide	Treatment, Finished	Monthly	0.2 µg/L
	Ozone	Treatment, Finished	Monthly	
Bromate (Method 300.0) ³	Ozone	Treatment, Finished	Monthly	5.0 µg/L
Chlorite (CIO ₂ ⁻)	Chlorine Dioxide	Treatment, Finished, and Distribution System (3)	Monthly	20 µg/L
Chlorate (ClO ₃ ⁻)	Chlorine Dioxide	Treatment, Finished, and Distribution System (3)	Monthly	20 µg/L
	Hypochlorite	Influent, Disinfectant Stock Solution, and Finished	Quarterly	
Haloacetonitriles-Four (HAN4) ²	All	Treatment, Finished, and Distribution System (4)	Quarterly	_
Dichloroacetonitrile (DCAN)	All	Treatment, Finished, and Distribution System (4)	Quarterly	0.5 µg/L
Trichloroacetonitrile (TCAN)	All	Treatment, Finished, and Distribution System (4)	Quarterly	0.5 µg/L
Bromochloroacetonitrile (BCAN)	All	Treatment, Finished, and Distribution System (4)	Quarterly	0.5 µg/L
Dibromoacetonitrile (DBAN)	All	Treatment, Finished, and Distribution System (4)	Quarterly	0.5 µg/L

Analyte	Plant Types Required to Monitor	Sampling Locations (# of Sampling Locations) ¹	Frequency	Minimum Reporting Level (MRL)
Cyanogen chloride (CNCI)	Chloramine	Finished and Distribution System (Max)	Quarterly	0.5 µg/L
Chloral Hydrate (CH)	All	Treatment, Finished, and Distribution System (4)	Quarterly	0.5 µg/L
Chloropicrin (CP)	All	Treatment, Finished, and Distribution System (4)	Quarterly	0.5 µg/L
Trichloropropanone (TCP)	All	Treatment, Finished, and Distribution System (4)	Quarterly	0.5 µg/L
Dichloropropanone (DCP)	All	Treatment, Finished, and Distribution System (4)	Quarterly	0.5 µg/L
	Ozone	Treatment, Finished	Quarterly	
Formaldehyde ⁴	Chlorine Dioxide	Treatment, Finished	Quarterly	5.0 µg/L
	Ozone	Treatment, Finished	Quarterly	5.0 µg/L
Acetaldehyde ⁴	Chlorine Dioxide	Treatment, Finished	Quarterly	
	Ozone	Treatment, Finished	Quarterly	5.0 µg/L
Butanal	Chlorine Dioxide	Treatment, Finished	Quarterly	
	Ozone	Treatment, Finished	Quarterly	5.0 µg/L
Glyoxal	Chlorine Dioxide	Treatment, Finished	Quarterly	
	Ozone	Treatment, Finished	Quarterly	
Methyl Glyoxal	Chlorine Dioxide	Treatment, Finished	Quarterly	5.0 µg/L
Pentanal	Ozone	Treatment, Finished	Quarterly	5.0 µg/L
	Chlorine Dioxide	Treatment, Finished	Quarterly	
Propanal	Ozone	Treatment, Finished	Quarterly	5.0 µg/L
	Chlorine Dioxide	Treatment, Finished	Quarterly	
Total Organic Halides (TOX)	All	Influent, Treatment, Finished, and Distribution System (4)	Quarterly	50 μg/L as Cl ⁻

Notes:

- 1 "Influent" refers to the point where the water enters the plant. "Treatment" may include one or multiple sample locations along the treatment process train, depending on the water quality parameter, DBP, and type of plant/disinfectant used. "Finished" refers to the point of exit from the plant. "Distribution System (4)" refers to the four points within the distribution system where samples were taken: the distribution system equivalent, two points with average residence time, and one point with maximum residence time. "Distribution System (3)" refers to three points in the distribution system where samples were taken: a location near the first customer, one point of average residence, and one point with maximum residence time. Plants that purchase water were also required to sample most DBPs at their plant influent. Plants that blend water sources within the treatment plant also monitored water quality parameters prior to blending.
- 2 No MRLs were set for alkalinity, total hardness, turbidity, temperature, free chlorine residual, total chlorine residual, chlorine dioxide, and ozone. Also, there are no MRLs for analyte summations (e.g., TTHM, HAA5) because they are determined by adding or averaging several individual concentrations, or for pH, which simply a direct measure.

- 3 Low levels of bromate may not be determined by EPA Method 300.0. Method 300.1 was written primarily to identify specific parameters (column, eluent, and injection volume) which could be employed to allow the quantitation of lower concentrations of bromate in drinking water. All 300.0 analytes are included in EPA Method 300.1; however, comparable low level measurements of bromate are not possible using the Method 300.0 standard operating conditions.
- 4 Aldehyde samples were also analyzed for optional aldehydes (benzaldehyde, decanal, hexanal, heptanal, nonanal, octanal).
- 5 Plants were encouraged, but not required, to monitor for these analytes.

Source: USEPA 1996c.

1.4.2 ICR Implementation Activities

EPA, along with other agencies, such as the American Water Works Association (AWWA) and the Association of Metropolitan Water Agencies (AMWA), provided technical assistance before and during the ICR. ICR reference manuals and videos were created to provide guidance on various technical aspects of the rule, such as microbial sample collection and database use. See Chapter 1 of the *Information Collection Rule Data Analysis* (McGuire et al. 2002) for a full listing of these materials. E-mail and telephone support was provided for questions during the early stages of the ICR implementation.

During ICR implementation, laboratories analyzing ICR samples for DBPs, DBP surrogates, and other water quality parameters were required to apply for ICR approval to ensure data quality. Over 400 commercial, utility, State, university, and Federal laboratories applied, of which 380 received approval. Initial approval was based on criteria developed by EPA and a panel of experts and was given based on method and analyte (see Chapter 1 of the *Information Collection Rule Data Analysis* [McGuire et al. 2002] for details on the approval criteria). To maintain approval status, laboratories had to successfully conduct six quarterly ICR performance evaluations (PE) studies. On-site audits were performed as an additional mechanism to maintain data quality.

1.4.3 ICR Sampling Plans

To ensure that ICR requirements were correctly applied, EPA required each system to submit an Initial Sampling Plan (ISP) for approval. The ISPs included Initial Sampling Schematics (ISSs) which were used to specify system-specific requirements. As reported in the *Information Collection Rule Data Analysis* (McGuire et al. 2002), after an initial review by EPA, nearly 80 percent of the ISPs required modifications such as correcting chemical additions or changing sampling locations. After a second review, nearly 90 percent of the ISPs were approved.

1.4.4 Data Management Activities

The ICR data were reported and tracked through the ICR Data Management System. The ICR Data Management System consists of three subsystems:

- ICR Water Utility Database System, used by PWSs to report data
- ICR Laboratory Quality Control (QC) Database System, used by independent laboratories to report information on sample quality control

• ICR Federal Database System (ICR FED), used to upload and maintain data from systems and laboratories in a central database

The data reported each month by ICR systems on diskettes included treatment unit process data for each ICR plant, and collection information and analytical results for each ICR sample. Once data were validated by EPA, they entered the ICR FED. The ICR FED is an OracleTM database available to the public.

1.4.5 Quality Assurance Activities

The ICR data were collected, analyzed, reported, and stored based on the *Quality Assurance Project Plan for the Implementation of the Information Collection Rule* that was finalized in July 1997 (USEPA 1997c). This Plan included data objectives and measurement criteria, training requirements, and instructions for records and documentation. It specified use of the *ICR Sampling Manual* (EPA 814-B-96-001), the *DBP/ICR Analytical Methods Manual* (EPA 814-B-96-002), and the *ICR Manual for Benchand Pilot-Scale Treatment Studies* (EPA 814-B-96-003). The Plan also specified oversight activities needed to ensure data quality and the data system to be used for collecting and reporting the measurement data. The ICR DBP occurrence and water quality parameter data were critical to the decision-making process. EPA provided oversight to ensure that procedures specified in the Plan were being followed:

- On a monthly basis, EPA received data on diskettes from systems and labs. The QC requirements established by the ICR were more extensive than those included in the laboratory analytical methods. Laboratories and systems were required to report most of the QC data to EPA along with the monitoring data.
- Once the data were uploaded into the Water Utility Database, the data were processed using validation algorithms. These algorithms tested whether the procedures were being followed by verifying, for example, that the laboratory was approved to perform the analysis and the sample was analyzed using an approved method. Information about the samples was used to cross-check data submitted by laboratories and water systems. Examples of validation failures include exceeding a sample holding time or failing the calibration standard. See Chapter 2 of the *Information Collection Rule Data Analysis* (McGuire et al. 2002) for a list of QC data used to validate ICR monitoring data. Laboratories and plants received reports containing validation failures and monthly results generated by ICR FED. They were given an opportunity to correct errors and resubmit data for the data validation process. Only data that met the QC criteria were maintained in ICR FED.
- As noted above, laboratories had to successfully conduct six quarterly ICR performance evaluations studies and on-site audits were also performed to maintain data quality.

Not only were the data collected with rigorous QA procedures in place, but the data and methods were also subject to extensive technical review. This level of attention to assessing the technical quality of the ICR data was used for several reasons. Most important was the recognition that these data were critical to the development of a future rule, and that importance was underscored by the data collection effort being specified in a separate federal rule with the force of law. It entailed substantial effort and expense on the part of water systems and the government. The data collection period was 18 months. Technical review occurred while data were being collected and enabled feedback, additional training, or other corrections to be made if particular water systems or laboratories appeared to have consistent data

problems. This technical review, conducted in conjunction with data collection, was more extensive than what would be possible during a peer review process after the monitoring was completed.

Some of the technical review steps undertaken were as follows:

- EPA set high QC criteria and monitored the failure rate for each data element and the reasons for failures so that EPA could adjust the validation process to accept some data that passed lower QC criteria or, if appropriate, could work with utilities and laboratories to fix the problems. (See Chapter 2 of the *Information Collection Rule Data Analysis* [McGuire et al. 2002] for a discussion of these and related data quality issues discussed below.)
- As noted above, EPA received monthly updates of data from systems and laboratories. EPA had automated some review of the technical quality or reasonableness of the data, such as whether the analysis was sensitive enough to meet the reporting requirements. Further, the process had built in the requirement for many fortified and duplicate samples so that precision could be verified and those data elements that did not pass could be removed. Overall, 92 percent of the analytical data met the ICR QC requirements (McGuire et al. 2002).
- After review by EPA, the data that had passed the QC criteria were released for analysis. The data were judged to be of sufficient quality based on the combination of using only reviewed and approved laboratories to conduct the analyses, using specific analytical methods, requiring all analyses to be performed within a specified amount of time, and continuously reviewing data throughout the 18 months of data collection. McGuire et al. (2002) stated that "[e]valuations of the QC data for DBPs and DBP surrogates indicate the national database... contain high-quality data suitable to support regulation development."
- In addition to the internal EPA process of reviewing, accepting, and releasing ICR data, these data were also carefully scrutinized upon release by EPA analysts, EPA contractors, and members of the M-DBP FACA Technical Work Group (TWG). The data were released for use in three 6-month blocks. Hundreds of statistical summaries and graphs were made available to the TWG through a web site that was used extensively. These reviewers were users of the information and many had extensive knowledge of the participating systems. The essentially unlimited availability of the data to interested experts ensured additional technical review of the data and ensured high data quality because any identified problems were discussed and brought to EPA's attention for explanation or correction.

1.4.6 Development of Auxiliary Databases

The M-DBP FACA Technical Work Group determined that data in ICR FED needed to be available in a more user-friendly format. To this end, EPA created seven auxiliary databases from ICR FED. The Auxiliary Database 1 (AUX1) (USEPA 2000d) is the primary Microsoft AccessTM database, containing all system- and plant-level data extracted from ICR FED, such as sampling and treatment operation data. The AUX1 database is structured "vertically," i.e., it is designed to facilitate analyses of a single parameter across all plants or subsets of plants.

Six other auxiliary databases were derived from AUX1 that focused on "horizontal" data, i.e., data that represented source water, plant, finished water, and in some cases, distribution data for an individual plant for specific analytes:

- Auxiliary Database 2 (AUX2): Contact Time (CT) and Disinfection
- Auxiliary Database 3 (AUX3): Enhanced Coagulation
- Auxiliary Database 4 (AUX4): Sludge Production
- Auxiliary Database 5 (AUX5): Washwater Return
- Auxiliary Database 6 (AUX6): Disinfection Byproducts
- Auxiliary Database 8 (AUX8): Input and output data for modeling

For the data in AUX1 to be presented in an user-friendly format, fields were added as necessary and some data manipulation occurred. Additional information on data transformation can be obtained from the dictionary and documentation of AUX1 (USEPA 2000m). The same data manipulation criteria were used when extracting all the auxiliary databases from AUX1. AUX7 was initially planned to assess source water quality issues, but was never created due to overlap with the other auxiliary databases.

1.4.7 Representativeness of ICR Data

It's important to characterize the geographic distribution of the ICR data as well as the time period over which the ICR data was collected. The geographic distribution is important to ensure the data set is covering most, if not all, of the major watersheds and hydrology conditions in the United States. The representativeness of the time period can be assessed by considering several factors including climate and source water quality of the systems included in the ICR. See Chapter 3 of the *Information Collection Rule Data Analysis* (McGuire et al. 2002) for further discussion of these topics. The national representativeness of ICR data is discussed in more detail in both the ICR handbook (McGuire et al. 2002) and the Stage 2 DBPR EA (USEPA 2005a).

Geographic Distribution

The geographic distribution of the surface and ground water systems represented in the ICR data is shown in Exhibits 1.2a and 1.2b. As mentioned previously, ICR monitoring was conducted by a census of disinfecting systems serving more than 100,000 people. Therefore, geographic coverage is generally quite broad though ICR systems were most concentrated in five States with large populations served by large systems (CA, NY, TX, FL, and PA). Four States (VT, MT, ND, and WY) had neither surface nor ground water ICR systems. Note that the majority of Florida's systems are served by ground water, though it ranks second in the total number of ICR systems per State. About half of the U.S. population served by CWSs is represented by ICR data (see Chapter 2, Exhibit 2.3 for estimate of population served by various system sizes).

Exhibit 1.2a Percentage of Surface Water Systems (by State) Sampled for the ICR



Note: Maps are not drawn to scale.





Note: Maps are not drawn to scale.

Climate and Source Water Quality

In Chapter 3 of the *Information Collection Rule Data Analysis* document (McGuire et al. 2002), the authors evaluated ICR data representativeness by comparing rainfall data and other weather patterns that occurred during the ICR monitoring period to historical weather patterns using data from the National Weather Service. The calendar year 1998 was the warmest and fifth wettest year on record in the United States since 1895. Rainfall amounts varied, however, across the country (approximately 22 percent of the country was much wetter than normal; however about 2 percent was much drier than normal). Due to this regional variations in temperature and rainfall, national trends and generalizations on the representativeness of the ICR data are not possible (McGuire et al. 2002).

1.4.8 Methods and Assumptions for Analyzing ICR Results

Description of Data Set Evaluated

The majority of ICR data described in this chapter are derived from the ICR AUX1 Database, CD version 5.0 (USEPA 2000d), representing monitoring results from 296 systems comprising 512 plants, including 11 plants with blended source water. Some analyses in Chapter 2 are based on data from AUX2 (USEPA 2000i) (results are from AUX1 unless otherwise noted). Data analyses in Chapters 2, 3, 4, and Appendix A of the document represent ICR results from the last 12 months, or last four quarters, of ICR collection period (January through December 1998).

Plant Source Water Type

Plants reported the following source water types for each month of the ICR: "surface water;" "ground water;" "mixed (or blended);" or "purchased water." For the purposes of this document, plant source water type is based on data from the last 12 months of the ICR. Because there are plants that reported more than one source water type during this period, designation of plant source water type was done using a hierarchical approach. Specifically, the plant source water type was designated by the following hierarchy: surface water, mixed, ground water, and purchased. In other words, if an ICR plant treated surface water for any month, it was classified as a surface water plant. Refer to Appendix B for the query language for source categorization (see the query "Plant Source Type, Last 12 Months").

ICR data analyses in the *Information Collection Rule Data Analysis* document (McGuire et al. 2002) and in other documents may have designated plant water source types differently. Because there are a small number of plants that reported more than one source type, the differences in methodology should not create a large discrepancy in results.

Plants With Multiple Quarterly Samples

Some of the plants in ICR data set reported multiple sampling results for a single quarter for a given distribution system location. In these circumstances, the data were averaged for the given sampling location and quarter. The averaged results were used in the plant screening analysis (see next section) and in all calculations. A total of 15 plants have at least one quarter that was analyzed in this manner, including all eleven blended plants. This does not apply to samples collected on a monthly basis.

Screening of Plants

For DBP analyses in Chapters 3 and 4 of this document, ICR plants are screened to include only those with at least three of the last four quarters of the ICR having at least three of four distribution system
sampling locations with both TTHM and HAA5 data. This screening was done to reduce the seasonal bias that could occur if TTHM and HAA5 data represented only one or two of the four quarters (e.g., if TTHM data represent the summer only, yearly average results would most likely be skewed high), or only one or two of the distribution system sampling locations (e.g., if data from the max location was missing, TTHM average results for the distribution system could be skewed low).

For all other analytes (e.g., TOC, temperature, etc.), plants were screened to include only those with at least nine of the last 12 months or three of the last four quarters of the ICR to reduce potential seasonal biases.

See Appendix B, Section B.3 for the query language for plant screening.

Assumptions for Data Below the MRL

Any analytical results below the MRL (a non-detect) for a particular water quality parameter, DBP, or disinfectant was assigned a value of zero. Because these levels below the MRL were assigned values of zero, the means for each water quality parameter, DBP, and disinfectant are probably slightly lower than they would be if the actual values were known and used in the calculations. In addition, median concentrations that appear to be zero are not necessarily zero but *are* below the MRL. There is no MRL for analyte summations (e.g., TTHM, HAA5) and DS Average values because they are determined by adding or averaging several individual concentrations, rather than by measuring directly. Therefore, if each THM, HAA, HAN4, or haloketone concentration is below its MRL, the resulting value for the corresponding TTHM, HAA5, HAA6, HAA9, HAN4, and haloketones is zero.

1.4.9 Documentation of ICR Data Analyses

ICR data are available to the public through the EPA Web site. Because there are different methods that could potentially be used to analyze ICR data, EPA has included several features in this document to ensure transparency and reproducibility of all ICR-based results:

- Section 1.4.8 described the overall methods and assumptions used by EPA to evaluate the ICR data.
- All tables and graphs in Chapters 2 through 4 show the number of observations (or N-count) used to generate results. The N-count will be the first data column in all tables and will be in either the title, axis heading, or legend of each chart.
- All Microsoft Access[™] queries (in Structured Query Language [SQL] code) used to extract ICR data from AUX1 are provided in Appendix B. Queries are organized alphabetically by query name.
- Query names, corresponding to queries in Appendix B, are included at the bottom of each applicable table and chart in Chapters 2 through 4.
- An Excel reference file is also provided for those analyses that were conducted in Microsoft Excel. All Excel files are included in the docket.

1.5 Other Data Sources

Occurrence data for medium and small water treatment plants were not included in the ICR data collection. Data were obtained from the ICRSS, NRWA Survey, the Water Utility Database (WATER:\STATS) (AWWA 2000), the Ground Water Supply Survey (GWSS) (USEPA 1983), and several States in order to examine the occurrence patterns of medium and small water treatment plants. Exhibit 1.3 briefly outlines these data sources, while the subsections that follow describe the sources in greater detail, including the level of quality assurance. Appendix C summarizes how each data source is used in this document and shows how the data quality objectives are met.

Exhibit 1.3 Summary of Non-ICR Occurrence Survey Data

Data Source	Number of Systems (or Plants) by Size (Population Served)	Data Collected	Time Frame	Geographic Representation
ICR Supplemental Survey (ICRSS) (Surface Water Only)	 47 plants serving 100,000 or more¹ 40 plants serving 10,000-99,999 40 plants serving fewer than 10,000 	 Raw source water - (Large Systems) TOC Raw source water - (Small & Medium Systems) TOC, UV₂₅₄, bromide, turbidity, pH, & temperature 	March 1999 - February 2000	Random national distribution by system size and surface water source type
NRWA Survey (Surface Water Only)	117 systems serving fewer than 10,000	 Population served and flows Raw source water - temperatures, turbidity, pH,and source water type, bromide, TOC, UV₂₅₄, alkalinity, calcium and total hardness Finished water-residence time estimate, total and individual THMs, individual HAAs and HAA5, HAA6, HAA9, TOC, UV₂₅₄, bromide, temperature, pH, free and total chlorine residual levels Treatment-unit processes, disinfectant used 	November 1999 - March 2000	Random national distribution
WATER:\STATS (Surface and Ground Water)	 219 systems serving 100,000 or more 623 systems serving 10,000- 99,999 30 systems serving fewer than 10,000 	 Population served and flows Raw source water - Water Quality Parameters (WQPs), Source water type Finished water - WQPs,TTHM,HAAs Treatment-unit processes, disinfectant used 	1996	Random national distribution
Ground Water Supply Survey	945 systems total (466 random, 479 nonrandom)	TOC and TTHM (one sample for each parameter at the entry point to distribution system)	December 1980 - December 1981	Combination of random national sample and nonrandom sample
State Data - Ground Water	562 systems serving fewer than 10,000	Distribution system TTHM occurrence data	Varies	AK, CA, FL, IL, NC, TX, WA ²
State Data - Surface Water	2,336 systems serving fewer than 10,000	Distribution system TTHM occurrence data	Varies	AK, CA, IL, MN, MS, NC, TX, WA ²

¹ Source type designations include flowing stream and lake/reservoir (except for seven large plants pre-selected). ² Over 50 percent of each State's systems are represented. In total there are approximately 20 percent of the nation's small systems included in these data. EPA believes that the data reasonably represent a full range of source water quality in small systems at the national level.

1.5.1 ICR Supplemental Survey

EPA conducted the ICRSS to supplement ICR information on microbial and byproduct occurrence. The ICRSS was conducted at 120 randomly selected plants, 40 of which were classified as small surface water plants serving fewer than 10,000 people, 40 as medium surface water plants serving 10,001 to 100,000 people, and 40 as large surface water plants serving more than 100,000 people. Seven very large systems (> 1 million people served) were also included in the survey effort. Monitoring was conducted for 12 consecutive months beginning in March 1999. Large systems collected protozoa and limited precursor data (i.e., TOC), while medium and small systems monitored water quality parameters (i.e., temperature, pH and alkalinity) and DBP precursors (i.e., TOC, UV_{254} and bromide). EPA used these data to compare relative treatability among different system size categories for achieving compliance with the Stage 2 DBPR regulatory alternatives. A discussion of the protozoa data is included in the *Draft Occurrence and Exposure Assessment for the LT2ESWTR* (USEPA 2005b).

These measurement data were generated based on the *Quality Assurance Project Plan for the Implementation of the Information Collection Rule Supplemental Surveys*, finalized in March 1999 (USEPA 1999c). The Plan employed a QA process similar to that used for ICR data, and covered measurement and data acquisition, assessment and oversight, and data validation and usability. Also similar to the review of ICR data, a technical review more extensive and rigorous than possible in a typical peer review process was implemented.

1.5.2 National Rural Water Association Survey

The National Rural Water Association (NRWA) Survey was conducted to provide information on DBPs and their precursors in small surface water systems. Results have been published in the document, *Summary Report: NRWA Small System Study of D/DBP* (Trax and Kramer, 2003).

The NRWA, in conjunction with EPA and NRWA State chapters, conducted a survey of 117 randomly selected small PWSs. A minimum number of 112 systems were targeted to ensure that the results from the survey (in particular, the 90 percent confidence intervals) would be statistically representative of the universe of small water systems. Also, because water temperature and other factors can affect DBP formation, the survey collected detailed treatment process information, source water quality data, and DBP samples for both a cold-weather period in 1999-2000 and a warm-weather period in 2000. NRWA data are presented in Chapter 3 and support the analyses of small systems.

The NRWA conducted this survey with the assistance of EPA (EPA did not direct this effort). EPA helped train those collecting the samples and provided QA review of the data compiled and presented by the NRWA. EPA-approved laboratories were used for the analysis of samples. The analytical data were generated based on the procedures used for the ICR. An extensive quality assurance protocol was followed to ensure high quality monitoring, management, and documentation of the analytical data. These included:

- Samples from ten percent of the 112 sites were replicated.
- Fifteen percent of the samples for each analyte were randomly replicated.
- The laboratory was provided with a THM "blank" sample. It was analyzed when results appeared erroneous or deviated greatly from expected values.

- All analytical methods and QA/QC procedures used in the survey were consistent with the requirements listed in the DBP/ICR Analytical methods Manual (EPA 814-B-96-002). For HAA9, the contractor had the flexibility to use Standard Method 6251B.
- The selection of the laboratory was based on the demonstration of historical ability to meet or exceed the QA/QC requirements.

1.5.3 The Water Industry Database (WATER:\STATS)

Published by the American Water Works Association (AWWA), WATER:\STATS is derived from the AWWA Water Industry Database based on information from the 1996 survey of approximately 900 water utilities. Most of these utilities are large water systems serving at least 10,000 people. The 1996 survey collected a range of financial and operational information on these utilities, including data on the occurrence of DBPs in finished water (however, many systems did not respond to all survey questions). WATER:\STATS does not contain individual sample results; rather, it contains summary statistics such as minimum, maximum, and average values that were reported by each system. The WATER:\STATS data used here are those that characterize relevant treatment and byproduct information for medium surface water plants (those serving between 10,000 and 100,000 people).

The survey was progressively improved upon since 1989, when WATER:\STATS was first developed by AWWA. Over the years, it has been technically reviewed by the AWWA and AWWARF Advisory Committees and by the Technical and Education Committees of the AWWA. These reviews have served to modify and improve the survey over time. Prior to sending the 1996 survey questionnaire out to all participants, it was field tested with 25 utilities and adjusted accordingly.

Responses to the survey questions were screened by a team of experts from AWWA to ensure they were applicable and pertinent. The AWWA staff also reviewed data for magnitude and units related issues. Standard procedures were adopted to identify apparent "outlier" data, with involved utilities contacted to determine if the outlier was legitimate or not (and was included or excluded accordingly).

1.5.4 Ground Water Supply Survey

There are few national studies of the occurrence of contaminants in ground water. Although two decades old, the GWSS, conducted by EPA from December 1980 through December 1981, remains one of the most extensive and useful studies of ground water. The GWSS sampled and analyzed levels of volatile organic compounds (VOCs) in ground water. Results are presented in the report, *The Ground Water Supply Survey: Summary of Volatile Organic Contaminant Occurrence Data* (USEPA 1983). The data from the GWSS are presented in Chapter 3 and support the analyses of medium and small systems.

The data were collected from 945 systems, approximately half selected randomly and half selected nonrandomly. Random selection was intended to provide a broad national perspective on the incidence of VOC contamination; the nonrandom selection allowed States to identify sites that were presumed to have high levels of VOCs for further investigation. Included in the sampling parameters were levels of finished water TOC and TTHM.

The random sample included 186 systems from a random list of systems serving a population of greater than 10,000, and 280 systems from a random list of systems serving a population of less than or equal to 10,000. The nonrandom sample consisted of 479 systems that were selected by State agencies. States were encouraged to choose systems for which no prior VOC data were available and believed to

have a high probability of contamination by VOCs, based on their knowledge of local conditions (e.g., proximity to landfills, industrial activity, etc.).

An extensive quality assurance protocol was followed to ensure high quality monitoring, management, and documentation of the analytical data. These protocols included:

- Laboratory analysis of EPA reference samples The reference samples contained known concentrations of compounds including four common trihalomethanes (THMs) and nine frequently detected VOCs. They were analyzed by the laboratory once a week for each instrument to determine whether the precision and accuracy of the instruments were within acceptable limits per the quality protocol.
- Analysis of duplicate samples by the laboratory Duplicate analyses were performed on at least 10 percent of the samples. The duplicate analyses were to agree within 40 percent for compounds present below 5 µg/L, and within 20 percent for compounds present above 5 µg/L, in order to comply with the quality protocol.
- Confirmatory analysis All samples found or suspected to contain purgeable aromatic and halocarbon compounds other than THMs were re-analyzed using different chromatographic columns that elute compounds in different orders. Samples containing chloroform at concentrations greater than 40 μ g/L were re-analyzed using the confirmatory column since chloroform concentrations at this level (i.e., equal to or greater than 40 μ g/L) could potentially mask the presence of 1,2-dichloroethane. Additionally, 5 percent of all samples were re-analyzed by gas chromatography/mass spectrometry (GC/MS) to identify or confirm unknown/tentatively known compounds.
- Blind samples EPA used five blind samples during the initial phase of the survey to evaluate the laboratory's ability to identify and measure specific compounds. The samples consisted of five different mixtures of compounds, spiked into organic-free distilled water. The contractor correctly identified the spiked compounds in every case.
- Analysis of duplicate samples by EPA Duplicate samples were collected in separate bottles and stored at EPA's laboratories. They were analyzed as an additional check on the contractor laboratory's results.

1.5.5 State Data

A number of State agencies have collected data on influent water quality and DBP occurrence for small surface water plants. As part of the data synthesis effort for small and medium systems, some of these States provided data sets to EPA. The Agency reviewed them for applicability to EPA's national analysis of DBP occurrence. The following States collected sufficient DBP occurrence data to include in further surface water analyses: Alaska, California, Illinois, Minnesota, Missouri, North Carolina, Texas, and Washington. In addition, seven States' data sets were used to analyze small ground water systems (Alaska, California, Florida, Illinois, North Carolina, Texas, and Washington). The data for both surface and ground water systems met several initial quality criteria:

• For each State's data set, the small surface water systems sampled by the State were representative of at least 50 percent of the total number of small surface water systems in the State.

• TTHM data were collected and reported in a manner that approximated a typical monitoring approach, and in some cases included individual species of THMs.

The data available from each State are not exactly comparable; some States reported individual sample data, while others reported only plant averages. Some of the data appear to be from distribution system locations, while other samples are from locations in the plant or from raw water. Samples in some States were collected quarterly, while in others the sample frequency ranged from one every two months to less than one per year.

These State occurrence findings are from existing sources and are typically summaries of data and summary statistics rather than the raw analytical data. Although a QA plan did not exist during data collection and data were not peer reviewed, it is assumed that the data were reviewed by States before submission to EPA. The usage of States data for characterizing national DBP occurrence for small surface water systems is discussed in the Stage 2 DBPR EA (USEPA 2005a). The States data are presented in Chapter 3 and support the analyses of medium and small systems.

1.6 Document Organization

The remainder of this document is organized into the following four chapters (with Chapter 5, the reference section) and three appendices.

- Chapter 2 <u>Use of Disinfectants in the United States</u>. The universe of systems using disinfectants and their population-served are presented by system size and source water type category. This chapter also presents information on disinfection use. An overview of disinfectant processes is provided, followed by information on the four most commonly used disinfectants: free chlorine, chloramine (combined chlorine), chlorine dioxide, and ozone. Each disinfectant is briefly described, including its method of application, use and distribution, advantages and disadvantages, dosage requirements, and potential byproducts.
- Chapter 3 <u>National Occurrence Data: Pre-Stage 1 Baselines</u>. This chapter presents data related to DBP occurrence in public drinking water supplies. Graphical presentations of source water quality parameters, disinfectant residuals, and DBPs are included. Data are from the ICR data set and other sources.
- Chapter 4 <u>National DBP Occurrence: Predicted Post-Stage 1 Baselines</u>. This chapter describes predicted post-Stage 1 occurrence for TTHM and HAA based on ICR data.
- Chapter 5 <u>References</u>.
- Appendix A <u>TTHM and HAA5 Speciation Occurrence Data</u>. This appendix supplements ICR analyses in Chapters 2 and 3 by showing results for TTHM and HAA5 species over the last 12 months of the ICR collection period.
- Appendix B <u>ICR Data Queries</u>. This appendix provides the Access[™] Queries (in SQL code) used in the data presentations in Chapters 2, 3, 4, and Appendix A. Queries are organized alphabetically by query name and include a one to two sentence description of their function.
- Appendix C <u>Assessment of Data Quality Objectives</u>. This appendix summarizes how each data source is used in this document and shows how the data quality objectives are met.

2. Use of Disinfectants in the United States

Many water treatment processes can remove or inactivate microorganisms, including pathogens that can cause waterborne diseases. Treatment is especially important for systems that use surface water sources or ground water under the direct influence of surface water (GWUDI). In many cases, surface water supplies receive discharges from upstream wastewater treatment plants, industrial facilities, stormwater runoff, or animal feed lots. In the treatment plant, certain treatment processes, such as sedimentation and filtration, remove most of the microorganisms that cause waterborne diseases. However, there is a need to inactivate the pathogens that pass through the filters, grow in the distribution system (e.g., biofilm growth), or breach the distribution system (e.g., entering through cross-connections or negative pressure). Surface water systems have relied primarily upon filtration supplemented by disinfection to control pathogens. Disinfection has been associated with major improvements in public health since it was widely adopted in the early 1900's.

This chapter describes the disinfection processes used in the treatment of drinking water and their effects on finished water quality. Sections 2.1 and 2.2 provide background information on the disinfection process and the resulting formation of DBPs, respectively. Section 2.3 provides the inventory of disinfecting community water systems (CWSs) with respect to source water type and population served. Section 2.4 shows data on the proportion of plants using various types of disinfection. Sections 2.5 through 2.8 describe the four main disinfectants used by drinking water systems: chlorine, chloramines, chlorine dioxide, and ozone. Included for each disinfectant is a description of chemistry and method of application, use and distribution, typical dosages, and potential byproducts. Chapter 3, Section 3.1.2, builds on this chapter by examining disinfectant residual concentrations in treated water. It is should be noted that UV disinfection is not included in this document because it is still a relatively new disinfection technique and the amount of available field data is limited. EPA specifically publishes an UV Disinfection Guidance Manual supporting the Long Term 2 Enhanced Surface Water Treatment Rule (USEPA 2005c).

2.1 Overview of Disinfection Processes

The 1995 *Community Water Systems Survey* (CWSS) (USEPA 1997b) reports that 99 percent of surface water systems in the United States provide some level of water treatment before distribution to customers, and 99 percent of these treatment systems use disinfection in the treatment process (disinfection is required for all surface water systems). Disinfection can be accomplished in several ways. The most common method used to achieve disinfection is to add a chemical disinfectant to the water. Disinfectants can be applied in the plant (this is referred to as primary disinfection) and/or after treatment (secondary disinfection), like filtration or sedimentation. Secondary disinfection ensures the presence of a disinfectant residual after treated water leaves the plant and enters the distribution system. Some systems use booster chlorination, the adding of chlorine or chloramines at a point within the distribution system, to raise the disinfectant residuals to required levels. The most commonly used disinfectants, in both plants and distribution systems, are chlorine and chloramines. Chlorine dioxide, ozone, and ultraviolet light (UV) (a non-chemical disinfection process) are also used on a limited basis to meet disinfection.

Chlorine, chloramines, ozone, and chlorine dioxide are oxidants, and, in addition to inactivating pathogens, are used to treat drinking water for the following purposes:

- Controlling Asiatic clams and zebra mussels (except for chloramines)
- Oxidizing inorganic material such as iron, manganese, and sulfides (except for chloramines)
- Preventing microbial regrowth in the distribution system and maintaining biological stability (except for ozone)
- Removing undesirable tastes and odors through chemical oxidation (except for chloramines)
- Improving coagulation and filtration efficiency
- Preventing algal growth in sedimentation basins and filters
- Oxidizing organic micropollutants such as pesticides and volatile organic compounds (except for chloramines)

The effectiveness of disinfection depends on the contact time (the amount of time a disinfectant is in contact with the water) and the residual disinfectant concentration. The efficacy of disinfection also depends on other factors, including pH, temperature, and the type of disinfectant used.

2.2 Disinfection Byproducts

Disinfectants react with naturally occurring organic matter (NOM) and inorganic matter to form DBPs. Three main types of DBPs are discussed in this document.

- Halogenated organic byproducts
- Organic oxidation byproducts
- Inorganic DBPs

Halogenated organic byproducts form during reactions with free chlorine or free bromine. Although bromine is not used as a disinfectant, bromide ions can be naturally present in water and, when oxidized, form free bromine. Organic oxidation byproducts, such as acetaldehyde, form during oxidation reactions with the disinfectants. Inorganic DBPs are usually formed during reactions with chlorine dioxide and ozone.

Temperature, pH, alkalinity, total hardness, turbidity, disinfectant type, bromide concentration, and the amount and composition of NOM (usually measured as total organic carbon, or TOC) affect the types and rates of DBP formation. It should be noted that many DBPs have been identified, but only a select subset (shown in Exhibit 2.1) were monitored during the ICR and are the focus of this analysis.

Halogenated Organic Byproducts ¹						
Trihalomethanes						
Chloroform (CHCl3)	Dibromochloromethane (DBCM)					
Bromodichloromethane (BDCM)	Bromoform (CHBr3)					
Haloacetic Acids	-Five (HAA5) Five					
Monochloroacetic acid (MCAA)	Dichloroacetic acid (DCAA)					
Trichloroacetic acid (TCAA)	Monobromoacetic acid (MBAA)					
Dibromoacetic acid (DBAA)						
<u> </u>	<u>1A6</u>					
HAA5	Bromochloroacetic acid (BCAA)					
<u> </u>	<u>149</u>					
HAA6	Bromodichloroacetic acid (BDCAA)					
Chlorodibromoacetic acid (CDBAA)	Tribromoacetic acid (TBAA)					
<u>Haloaceton</u>	<u>itriles (HAN4)</u>					
Dichloroacetonitrile (DCAN)	Bromochloroacetonitrile (BCAN)					
Dibromoacetonitrile (DBAN)	Trichloroacetonitrile (TCAN)					
<u>Halok</u>	<u>etones</u>					
1,1-Dichloropropanone	1,1,1-Trichloropropanone					
Ot	<u>hers</u>					
Chloropicrin (CP)	Chloral Hydrate (CH)					
Cyanogen Chloride (CNCI) Total Organic Halides (TOX)						
Organic Oxida	Organic Oxidation Byproducts					
Aldehydes						
Formaldehyde	Acetaldehyde					
Propanal	Butanal					
Pentanal	Glyoxal					
Methyl Glyoxal						
Inorganic Byproducts						
Chlorate Ion	Chlorite Ion					
Bromate Ion						

Exhibit 2.1 List of Disinfection Byproducts Measured During the ICR

¹ Not all individual organic halides could be measured during the ICR. TOX is used to estimate the total quantity of dissolved halogenated organic material in water. Source: USEPA 1996c.

2.3 Inventory of Disinfecting Water Systems and Population Served

Both CWSs and nontransient noncommunity water systems (NTNCWSs) that disinfect their water supplies, as well as transient noncommunity water systems that use chlorine dioxide, will be regulated under the Stage 2 DBPR. All surface water systems are required to disinfect, but only an estimated 68 percent of ground water CWSs and 37 percent of ground water NTNCWSs disinfect (USEPA 2005a). Exhibit 2.2 shows the combined CWS and NTNCWS estimated system size distribution of disinfecting systems, classified by source water type (systems using GWUDI are included in the surface water category) and by population served. Exhibit 2.2 shows that approximately 76 percent of disinfecting CWSs and NTNCWSs are ground water systems.

System Size	Ground Water		Surface Water		Total	
(Population Served)	(Percent of	Total)	(Percent of	Total)	(Percent of	Total)
Small (< 10,001)	37,980	(73.6%)	9,921	(19.2%)	47,901	(92.8%)
Medium (10,001 - 100,000)	1,365	(2.6%)	2,013	(3.9%)	3,378	(6.5%)
Large (>100,000)	63	(0.1%)	290	(0.6%)	353	(0.7%)
Total	39,408	(76.3%)	12,224	(23.7%)	51,632	(100.0%)

Exhibit 2.2 Number (and Percent) of Disinfecting CWSs and NTNCWSs

Detail may not add due to independent rounding.

Notes: The "surface water" designation includes GWUDI systems.

Percent disinfecting based on 1995 CWSS, as summarized in the Drinking Water Baseline Handbook, and adjusted for potential impacts of the Ground Water Rule. See Chapter 3 of the Stage 2 DBPR Economic Analysis (USEPA 2005a) for further details.

Source: Derived from Chapter 3, Exhibit 3.2 of the Stage 2 DBPR Economic Analysis (USEPA 2005a).

Exhibit 2.3 shows other size distribution findings. While the number of systems are primarily small ground water systems, the majority of people are served by large surface water systems: 37 percent of the population is served by ground water systems, and 63 percent of the population is served by surface water. This is because most large systems serving more than 100,000 people are surface water systems.

Exhibit 2.3 Population Total (and Percent) Served by Disinfecting CWSs

System Size	Ground Water		Surface Water		Total	
(Population Served)	(Percent of Total)		(Percent of Total)		(Percent of Total)	
Small (< 10,001)	29,413,975	(11.6%)	8,197,640	(3.2%)	37,611,615	(14.8%)
Medium (10,001 - 100,000)	37,986,723	(14.9%)	38,616,140	(15.2%)	76,602,863	(30.1%)
Large (>100,000)	26,392,250	(10.4%)	113,871,860	(44.7%)	140,264,110	(55.1%)
Total	93,792,948	(36.9%)	160,685,640	(63.1%)	254,478,588	(100.0%)

Detail may not add due to independent rounding.

Notes: The "surface water" designation includes GWUDI systems.

Percent disinfecting based on 1995 CWSS, as summarized in the Drinking Water Baseline Handbook, and adjusted for potential impacts of the Ground Water Rule. See Chapter 3 of the Stage 2 DBPR Economic Analysis (USEPA 2005a) for further details. NTNCWSs are typically schools, restaurants, etc., and their population is already counted in the CWS population, thus only population served by CWSs is shown in this exhibit.

Source: Derived from Chapter 3, Exhibit 3.3 of the Stage 2 DBPR Economic Analysis (USEPA 2005a).

Exhibits 2.2 and 2.3 also show the distribution of systems and population between different size categories. Approximately 93 percent of all disinfecting CWSs and NTNCWSs are small systems serving less than 10,000 people, while fewer than one percent are large systems serving more than 100,000 people. Although there are many more small systems than large in the United States, an estimated 140 million people (55 percent) are served by large disinfecting systems, 77 million (30 percent) by medium disinfecting systems, and only 38 million (15 percent) by small disinfecting systems.

2.4 Disinfectant Types

This section presents data on chemical disinfection practices among large surface and ground water plants as derived from the Information Collection Rule Auxiliary Database 1 (ICR AUX1) (USEPA 2000d). It also presents disinfectant dose data for chlorine, ozone, and chlorine dioxide from the Information Collection Rule Auxiliary Database 2 (ICR AUX2) (USEPA 2000i). See Chapter 1, section 1.4.6 for a description of these databases.

In the ICR databases, disinfectant types associated with a treatment plant are classified based on disinfectant usage within the plant and distribution system. At the plant level, five disinfectant types are defined in the ICR AUX1 and AUX2 databases as:

- **CL2**—Free chlorine (Cl₂) when only Cl₂ is used as a disinfectant.
- **CLM**—Chloramine (CLM) when Cl₂ and ammonia (NH₃) are added simultaneously into a unit process in the plant where no earlier point of chlorination exists.
- **CL2_CLM**—Cl₂ followed by CLM when NH₃ is added after free chlorine has previously been applied in one or more preceding unit processes.
- **CLX**—Chlorine dioxide (ClO_2) if ClO_2 is used anywhere in the plant.
- **O3**—Ozone (O_3) if O_3 is used anywhere in the plant.

At the distribution system level, two disinfectant types are defined (i.e., CL2 and CLM) according to the disinfectant type applied at the last disinfectant application point before the entry point to the distribution system.

In order to characterize disinfection practices of surface water plants, the ICR AUX2 database was used to derive information for plants that reported both plant- and distribution system-level disinfectant use for the last 12 months of the ICR collection period. Because some plants switched disinfectants during the 12-month period, the analysis was done for each plant-month individually. Exhibit 2.4 shows the findings of the analysis for surface water plants for each combination of plant and distribution system disinfectant for 3,927 plant-months. In Exhibit 2.4, the letters before the '/' represent the primary disinfectant, while the letters after the '/' represent the secondary disinfectant. For example, CL2/CLM would mean a plant that uses chlorine for primary disinfection and chloramine for secondary disinfection. Chapter 15, Table 15.1, in the *Information Collection Rule Data Analysis* document (McGuire et al. 2002) provides additional information on the type of disinfectants used for different treatment plant types (e.g., conventional softening, unfiltered).

For ground water plants, the ICR AUX2 database was also used to characterize disinfection practices. Information was extracted for ground water plants that reported both plant- and distribution system-level disinfectant use for the last 12 months of the ICR collection period. Exhibit 2.5 shows the results of the ground water plant analysis for chlorine only, chloramines only, and each combination of plant and distribution system disinfectant for 647 plant-months. The "CL2 only" category includes plants that reported chlorine use for both the plant and distribution system category, and includes plants that reported chlorine use only in the distribution system.





Source: ICR AUX1 Database (USEPA 2000d).

Query: Screened Plant Disinfectant Type. See Appendix B for details.





Source: ICR AUX1 Database (USEPA 2000d). Query: Screened Plant Disinfectant Type. See Appendix B for details.

Among medium surface water plants, chlorine is the most common disinfectant (see Exhibit 3.34, which compares disinfectant use in medium and large plants). The National Rural Water Association (NRWA) Survey indicates that almost all small surface water systems use free chlorine (see Exhibit 3.43).

2.5 Chlorine

Chlorine is the most commonly used disinfectant in public water systems in the United States. Through filtration and chlorination, waterborne diseases, including typhoid and cholera, have been virtually eliminated in this country. For example, in only four years (between 1911 and 1915), the number of typhoid cases in Niagara Falls, New York dropped from 185 deaths for every 100,000 people to nearly zero following the introduction of filtration and chlorination (White 1986).

Disinfection with chlorine is simple, economical, efficient, measurable, and practical. Several forms of chlorine are available for use as a disinfectant.

- Chlorine gas (Cl₂)
- Sodium hypochlorite (liquid) (NaOCl)
- Calcium hypochlorite (tablet, granular, or powdered) (Ca(OCl)₂)

2.5.1 Description of Chemistry

The chemistry is similar for all forms of chlorine; they all react with water to form disinfecting agents. Chlorine hydrolyzes in water to form hypochlorous acid (HOCl). HOCl is a weak acid and ionizes to yield hypochlorite ion, or OCl⁻. Free residual chlorine is the sum of HOCl and OCl⁻ concentrations; the relative quantity of each depends on pH. Both hypochlorous acid and hypochlorite inactivate or kill pathogens, but hypochlorous acid is more effective.

Upon addition to water, free chlorine chemically reacts with constituents in the water by various mechanisms. Chlorine oxidizes soluble iron, manganese, and sulfides typically found in drinking water sources. Once oxidized, the resulting products precipitate and are primarily removed by clarification and filtration processes. When chlorine reacts with natural organic matter in the water, it reacts with electron-rich sites to form halogenated organic byproducts (e.g., trihalomethanes and chlorophenols), some of which have been shown to be possible human carcinogens (Weisel et al. 1999). Chlorine also oxidizes organic matter to form compounds that do not contain a halogen, such as aldehydes, carboxylic acids, ketones, and alcohols (Richardson 1998). The occurrence of halogenated byproducts has been studied the most because halogenated DBPs are easily detected.

The three forms of chlorine that are typically used at water treatment plants (chlorine gas, sodium hypochorite, and calcium hypochlorite) are described below.

Chlorine gas is often referred to as elemental chlorine. Chlorine is produced, collected, purified, compressed, cooled, packaged, and shipped as a liquefied gas under pressure. Systems then inject chlorine gas into the water stream, where hydrolysis and ionization (as described above) produce the disinfecting agents.

Sodium hypochlorite is produced by reacting chlorine with sodium hydroxide. Sodium hypochlorite solutions are also referred to as liquid bleach or Javelle water. Generally, commercial or industrial grade solutions have hypochlorite strengths of 10 to 16 percent. Low concentrations (i.e., 5.25 percent or less) are sold as common household bleach. The stability of a sodium hypochlorite solution depends on the hypochlorite concentration, storage temperature, time in storage, impurities, pH, and exposure to light. Decomposition of hypochlorite solution over time can affect the feed rate and dosage, as well as produce undesirable byproducts such as chlorite or chlorate ions (Gordon et al. 1995). Because of these storage problems, many systems are investigating onsite generation of sodium hypochlorite in lieu of purchasing hypochlorite stock supplies from a manufacturer or vendor.

Calcium hypochlorite is a crystal and can be produced by combining equivalent amounts of sodium hypochlorite and calcium chloride (known as the Perchloron process). A slurry of lime and caustic soda is chlorinated and cooled so that crystals are formed. These crystals are centrifuged, then added to a chlorinated lime slurry; when warmed, the calcium hypochlorite precipitates. Generally, the final product contains up to 70 percent available chlorine and less than 3 percent lime (White 1992). Storage of calcium hypochlorite is a safety consideration. It

should never be stored where it is subject to heat, allowed to contact any easily oxidized organic material, or become wet (moisture can trigger a reaction, creating heat and possibly fire).

Based on analysis of the ICR AUX2 data, gaseous chlorine is by far the most common form of chlorine used for water system disinfection (chlorine was used in its gaseous form 91 percent of the time). See the *Information Collection Rule Data Analysis* document (McGuire et al. 2002) for more details. However, small systems are more likely to use sodium hypochlorite.

2.5.2 Use and Distribution

Chlorine gas feeders used to treat drinking water can be either direct feed or solution feed. Direct gas feeders deliver chlorine gas under pressure directly to the point of application. Because direct feeders are less safe than solution feed chlorinators, solution feed is typically used. In a solution feeder, chlorine gas is metered under vacuum conditions and mixed with water in an injector to produce a chlorine solution, which is injected at the appropriate application point(s). With this type of system, the flow of chlorine gas automatically shuts off if there is a loss of vacuum, stoppage of the solution discharge line, or loss of operating solution water pressure. This safety mechanism is important because chlorine gas released into the atmosphere can cause acute health problems or even death if inhaled.

Sodium hypochlorite is normally fed directly with a motor-driven positive displacement-type chemical metering pump(s) to the appropriate application point(s). Although unusual, feeding sodium hypochlorite using a hydraulic injector or simple gravity flow is possible.

When calcium hypochlorite is used as a treatment process for continuous disinfection, it is often mixed with water to form a dilute hypochlorite solution and is typically fed in the same manner as sodium hypochlorite. For spot disinfection in a basin or pipe, calcium hypochlorite tablets are deposited in the appropriate location, water is added, and the tablets allowed to dissolve to form a liquid hypochlorite solution.

According to the 1995 *Community Water Systems Survey* (USEPA 1997b), most surface water and ground water systems that have primary disinfection use chlorine. Exhibits 2.4 and 2.5 (displayed previously) show that 54 percent of large ICR surface water and 85 percent of large ICR ground water systems use chlorine. Additionally, these exhibits show that chlorine is also the most widely used secondary disinfectant.

2.5.3 Pros and Cons

The following list presents selected advantages and disadvantages of using chlorine to disinfect drinking water (Masschelein 1992; DeMers and Renner 1992).

- Advantages
 - Chlorine is an effective biocide.
 - Chlorine oxidizes soluble iron, manganese, and sulfides.
 - Chlorine enhances color removal.
 - Chlorine controls taste and odor.
 - The use of chlorine is the easiest and least expensive disinfection method, regardless of system size.

- Chlorine is the most widely used disinfection method and, therefore, the most well known.
- Chlorine is available as calcium and sodium hypochlorite, which are more advantageous for smaller systems than chlorine gas because they are easier to use, safer, and need less equipment compared to chlorine gas.
- Chlorine provides a residual, making it a good secondary disinfectant.
- Disadvantages
 - Chlorine forms both halogenated and non-halogenated organic byproducts (some of which pose health concerns).
 - Chlorine gas is a hazardous and corrosive gas, and special leak containment and scrubber facilities could be required to ensure safety.
 - Sodium hypochlorite degrades over time and with exposure to light (which diminishes its treatment effectiveness).
 - Sodium hypochlorite is a corrosive chemical.
 - Calcium hypochlorite requires proper storage. It must be stored in a cool, dry place to reduce potential reactions. Also, an antiscalant chemical may be needed since impurities may cause a precipitate to form.
 - Higher concentrations of hypochlorite solutions are unstable and will produce chlorate as a decomposition byproduct.
 - Hypochlorite can contain bromate as a contaminant, resulting in an inadvertent introduction of low concentrations of bromate to drinking water.
 - Chlorine is less effective in water with higher pH.
 - Chlorine forms biodegradable oxygenated byproducts that can lead to regrowth of biological material in the distribution system.

Because of the variety of forms and dosage of chlorine and their different usage depending on system size and water quality, not all of these advantages and disadvantages apply to all systems.

2.5.4 Dose Ranges and Points of Application

Two key operational parameters that affect DBP formation are disinfectant dose and point of application. The chlorine dose range guideline used in reviewing public water systems' (PWSs) ICR initial sampling plans was based on dosages provided in engineering design manuals and published articles (see the *Occurrence Assessment for Disinfectants/Disinfection Byproducts in Public Drinking Water Supplies* [USEPA 1998c] for further information). The combination of chlorination at the treatment plant and strategic locations in the distribution system may be more effective at maintaining residuals than an equivalent single dosage at the treatment plant (Tryby et al. 1999). Public health benefits of booster chlorination can include decreased DBP formation (since lower residuals can be achieved in the finished water) and better control of biological regrowth and biofilm formation in the distribution system.

Exhibit 2.6 illustrates the difference in total chlorine dose in large surface water plants using only free chlorine versus those using chloramines (median of 2.7 mg/L as Cl_2 for chlorine-only plants versus a median of 5.0 mg/L as Cl_2 for chloramine plants). Chapter 15 in the *Information Collection Rule Data Analysis* document (McGuire et al. 2002) provides additional information on chlorine dose for different plant types (e.g., direct filtration, softening) and different influent TOC concentrations. Higher chlorine doses applied in surface water plants using chloramines may be necessary to achieve adequate disinfection due to higher levels of organic material. Also, higher chloramine residuals can be maintained

without the subsequent taste and odor complaints or the same increase in DBP formation in comparison to free chlorine. Finally, higher doses are need to meet CT requirements for surface water systems.

Exhibit 2.7 shows the difference in total chlorine dose in ground water plants using only free chlorine versus those using chloramines (median of 1.6 mg/L as Cl_2 for chlorine-only plants versus a median of 5.0 for chloramine plants). Higher chlorine doses applied in ground water plants using chloramines may be a result of lower levels of organic material allowing for greater chlorine doses without the subsequent increase in chlorinated DBP levels. Also, higher chloramine residuals can be maintained without the subsequent taste and odor complaints or the same increase in DBP formation in comparison to free chlorine. There are no CT requirements for ground water systems.



Exhibit 2.6 Cumulative Distributions of Mean Total Chlorine Dose for Surface Water Plants





Exhibit 2.7 Cumulative Distributions of Mean Total Chlorine Dose for Ground Water Plants

Source:ICR AUX2 Database (USEPA 2000i).Query:Screened SW Plant-Mean CL2 Doses (w AUX2). See Appendix B for details.

Exhibit 2.8, taken from Table 15.3 in the *Information Collection Rule Data Analysis* document (McGuire et al. 2002), shows the number of disinfectant application points for various types of surface water plants using free chlorine only. The data indicate that most plant types used either one or two application points. Approximately 10 percent of direct filtration, in-line filtration plants, and conventional plants used three Cl_2 application points. Plants with multiple application points were most likely using Cl_2 to address multiple treatment objectives (e.g., disinfection, preoxidation, taste and odor control, and prevention of microbial growth within unit processes).

Exhibit 2.8 Number of Disinfection Points in Plants Using Only Free Chlorine by Plant Type

	Plant-months (%)				
Type of plant	1 location	2 locations	3 locations	>3 locations	
Conventional (N=1696)	37	53	10	0	
Softening (N=74)	51	49	0	0	
Direct/in-line filtration (N=206)	41	49	10	0	
Unfiltered (N=45)	47	53	0	0	
Other† (<i>N</i> =27)	100	0	0	0	

Source: Information Collection Rule Data Analysis (McGuire et al. 2002). Notes: Based on data collected during the last 12 months of ICR monito

Based on data collected during the last 12 months of ICR monitoring. † Includes one membrane, one slow sand filtration, and two other plants.

Exhibit 2.9, taken from Figure 15.3 in the *Information Collection Rule Data Analysis* document (McGuire et al. 2002), shows the proportion of plants using specific chlorine application locations (e.g., rapid mix). Results are shown separately for subsets of plants with one, two, or three points of application. Results for the three subsets were consistent: plants apply disinfection primarily at the clearwell, at a point just prior to filtration, or at the rapid mix stage. For plants with one application point, rapid mix is the application point 36 percent of the time, the point just prior to filtration 28 percent, and the clearwell is used 27 percent of the time. For plants with two application points, the rapid mix is used 53 percent, the point just prior to filtration 32 percent, and the clearwell is used 80 percent of the time. Given the prevalence of the rapid mix stage and the point just prior to filtration points, chlorine-only systems may have some flexibility to move the point of chlorination to reduce the formation of DBPs. Moving the point of chlorination until after the sedimentation, flocculation, and filtration allows chlorine to be added after the majority of DBP precursors have been removed from the water, thereby minimizing DBP formation. However, this may hinder overall disinfection, taste and odor control, coagulation, and particulate removal (in the case of biofiltration removing assimilable oxygenated byproducts).

Exhibit 2.9 Number of Chlorine Application Locations in Conventional Plants Using Only Free Chlorine



Cl₂ Application Points in Treatment Plants

2.5.5 Byproducts

Although disinfection of water inactivates microbes that can transmit disease, it has the drawback of producing hundreds of DBPs, some of which are considered to be harmful to humans (Carlson and Hardy 1998; Chen and Weisel 1998). Exhibit 2.1 listed the halogenated organic byproducts that were measured during the ICR. The two most abundant groups of DBPs are trihalomethanes (THMs) and haloacetic acides (HAAs) (Weisel et al. 1999; Hoyer 1998).

Halogenated organic byproducts form when NOM reacts with free chlorine or free bromine. Free chlorine is normally introduced into water directly as a primary or secondary disinfectant. Free bromine results from the oxidation of naturally occurring bromide ion by chlorine or may be a contaminant in chlorine feedstock. Factors affecting the rate of formation and concentration of halogenated organic DBPs include type and concentration of NOM, form and dose of chlorine, contact time, bromide ion concentration, pH, organic nitrogen concentration, and temperature (Chen and Weisel 1998; Clark and Sivaganesan 1998). Organic nitrogen significantly influences the formation of nitrogen-containing DBPs, including the haloacetonitriles and halopicrins (Reckhow et al. 1990; Hoigne and Bader 1988). See Chapter 1 for a full discussion of factors affecting DBP formation.

Other DBPs can result from impurities in feed chemicals. Sodium hypochlorite is formed by combining chlorine gas and sodium hydroxide. Both chemicals are manufactured by electrolysis of sodium chloride (table salt), which can contain naturally occurring impurities, such as bromide ions, that are difficult to remove. While manufacturing sodium hypochlorite, bromide is converted to bromate, which has been found in sodium hypochlorite solutions (The Chlorine Institute 2004).

Source:Information Collection Rule Data Analysis (McGuire et al. 2002).Notes:Based on data collected during the last 12 months of ICR monitoring.

Pre=pretreatment; RAP=rapid mix; FLC=flocculation; SED/SCC= sedimentation/clarifier; DCB=disinfection contact basin; FIL=filter; CLR/ABS=clearwell; OTH=other.

2.6 Chloramines

Chloramines were first considered for use in disinfection after scientists observed that disinfection still occurred when ammonia was present, even though free available chlorine had dissipated. This lingering disinfection was caused by inorganic chloramines.

Chloramines were used regularly for disinfection during the 1930s and 1940s to provide a residual disinfectant and to control taste and odor. Because of an ammonia shortage during World War II, however, the popularity of chloramination declined. In recent years, choramines were recognized as being more stable than free chlorine in the distribution system and, consequently, were found to be effective in controlling bacterial regrowth in the distribution system (LeChevallier et al. 1996). The concern over halogenated organic byproduct (THM and HAA) formation in water treatment and distribution systems has increased interest in chloramines because they react differently with NOM than chlorine, generally producing lower concentrations of DBPs (Symons et al. 1998). Currently, monochloramine is used to disinfect drinking water in approximately 25 percent of U.S. municipalities (Kool et al. 1999).

2.6.1 Description of Chemistry

Chloramines are formed by the reaction of ammonia with aqueous chlorine. In aqueous solutions, hypochlorous acid from the chlorine reacts with ammonia to form inorganic chloramines in a series of competing reactions. In these reactions, monochloramine (NH₂Cl), dichloramine (NHCl₂), or nitrogen trichloride (NCl₃), also referred to as trichloramine, are formed. These competing reactions depend primarily on pH and are controlled to a large extent by the chlorine:ammonia nitrogen ratio (Cl₂:NH₃-N). Temperature and contact time also regulate this reaction. Monochloramine is formed primarily when the applied Cl₃:NH₂-N ratio is less than 5:1 by weight. When certain ratios of chlorine and ammonia nitrogen are present, chloramines may not form, and ammonia and chlorine may be converted to other molecules that do not act as disinfectants and are not detected when chlorine residual is measured. For instance, as the applied Cl₂:NH₃-N ratio increases from 5:1 to 7.6:1, a "breakpoint" reaction occurs, reducing the residual chloramine and ammonia nitrogen level to a minimum. Breakpoint chlorination results in the formation of nitrogen gas or nitrate and hydrochloric acid. At Cl₂:NH₃-N ratios above 7.6:1, free chlorine and nitrogen trichloride are present; being quite volatile, the latter usually dissipates. To avoid breakpoint reactions, utilities normally maintain a Cl₂:NH₃-N ratio of between 3:1 and 5:1 by weight. A ratio of 6:1 is actually optimum for disinfection because dichloramine predominates (dichloramine is a stronger disinfectant than monochloramine), but maintaining a stable operation at that point on the breakthrough curve is difficult. Therefore, as noted above, a Cl₂:NH₃-N ratio of 3:1 to 5:1 is typically accepted as optimal for chloramination.

2.6.2 Use and Distribution

Monochloramine is used primarily as a secondary disinfectant for maintaining a residual in the distribution system. Monochloramine can be formed by adding ammonia first and then chlorine, by adding chlorine first and then ammonia, or by concurrently adding both reactants. Ammonia is added first when the formation of objectionable taste and odor compounds caused by the reaction of chlorine and organic matter are a concern. Inactivation for bacteria is better when it is mixed in water to be treated rather than using preformed chloramines because you get the inactivation properties of chlorine, while combining free chlorine with ammonia instead of organics. Currently, most drinking water systems add chlorine first and then ammonia, in order to meet the EPA Surface Water Treatment Rule (SWTR)

disinfection requirements. The point of ammonia addition typically is selected to "quench" the free chlorine residual after the optimal contact time has been achieved.

2.6.3 Pros and Cons

The following list highlights selected advantages and disadvantages of using chloramines as a method of disinfecting drinking water (Masschelein 1992).

- Advantages
 - The monochloramine residual is more stable and lasts longer than free chlorine or chlorine dioxide—thereby providing better bacterial regrowth protection in the distribution system.
 - Chloramines can be very effective in addressing taste and odor problems.
 - Chloramines are inexpensive and easy to produce.
 - Production of chlorinated DBPs is minimized if $Cl_2:NH_3$ ratio is maintained at 3:1 to 5:1.
- Disadvantages
 - The disinfecting properties of chloramine are not as strong as other disinfectants, such as chlorine, ozone, and chlorine dioxide.
 - Chloramines cannot oxidize iron, manganese, or sulfides.
 - When using chloramine as the secondary disinfectant, it may be necessary to periodically convert to free chlorine for control of nitrification, which can be caused by excess ammonia in the distribution system.
 - Dichloramines can pose problems for taste and odor if the Cl₂:NH₃-N ratio isn't maintained between 3:1 and 5:1.
 - Two separate storage, feed, and control systems (one for chlorine, one for ammonia) must be used.
 - As Cl_2 :NH₃ ratio approaches the breakpoint, the greater the potential for DBP formation.

Not all of these advantages and disadvantages apply to all systems, depending on the dosages of chloramine and water quality.

2.6.4 Dose Ranges and Points of Application

The normal primary disinfection dose range for monochloramine is 1.0 to 4.0 mg/L. The minimum dosage of monochloramine in the distribution system is typically 0.5 mg/L (Texas Natural Resource Conservation Commission 1996). Exhibit 2.6 showed the cumulative distributions of mean chloramine dose for surface water plants. Another way to characterize total chlorine dose is by Cl₂:NH₃-N weight ratios. These weight ratios determine the species of chloramines formed (e.g., monochloramine, dichloramine, trichloramine). Exhibit 2.10 shows the distribution of Cl₂:NH₃-N weight ratios in plants using chloramines. The distributions indicate that approximately 95 percent of plants using chloramines had a plant average Cl₂:NH₃-N weight ratio above 2.5 (McGuire et al. 2002).



Exhibit 2.10 Cl₂:NH₃-N Weight Ratios in Surface Water CL2_CLM and CLM Plants

(Plant Averages [indicated by o], Minimums, and Maximums)

Source: Information Collection Rule Data Analysis (McGuire et al. 2002).

Approximately 92 percent of ICR plants using CL2_CLM, free chlorine followed by the application of ammonia, have one point of application of ammonia and the remaining 8 percent have two points of application of ammonia. For CLM plants, 78 percent have one point of application and 22 percent have two points of application. Figures 15.4A and B in the *Information Collection Rule Data Analysis* document (McGuire et al. 2002) show the point of application of ammonia for CL2_CLM and CLM plants. For CL2_CLM plants with one point of application, 53 percent applied ammonia at the clearwell, while approximately 19 percent applied ammonia at the rapid mix stage (the remaining plants added ammonia during flocculation, sedimentation, or prior to filtration). For plants with two points of application, most plants applied ammonia at the rapid mix and clearwell points. For CLM plants, the rapid mix point was the predominant point of application for plants with both one and two points of application. The predominance of the rapid mix point indicates that ammonia is being added early in the treatment train to minimize DBP formation or to increase the contact time of chloramines throughout the treatment plant.

2.6.5 Byproducts

The effectiveness of chloramines in controlling DBP production depends upon a variety of factors, notably the chlorine to ammonia ratio, the point of addition of ammonia relative to that of chlorine, the effectiveness of mixing, and pH levels in the water.

Direct reactions between monochloramine and organic matter in water produce very few halogenated organic compounds. However, some dichloroacetic acid can be formed, and cyanogen chloride formation is greater than with free chlorine (Jacangelo et al. 1989; Smith et al. 1993; Cowman and Singer 1994; Symons et al. 1998). If chlorine and NH_3 are added separately to water (not preformed), then some free chlorine is available to react with organic matter. Another potential source of free chlorine is monochloramine, which slowly hydrolyzes to free chlorine in an aqueous solution. Therefore, halogen-substitution reactions occur even when pre-formed monochloramine is used (Rice and

Gomez-Taylor 1986). The closer the $Cl_2:NH_3$ -N ratio is to the breakpoint, the greater the formation of DBPs (Speed et al. 1987).

The application of chloramines results in the formation of total organic halide (TOX), which includes unidentified organic byproducts. However, TOX formation occurs to a much lesser degree than it would given an equivalent dose of free chlorine. Little is known about the nature of these byproducts, except that they are more hydrophilic and larger in molecular size than the organic halides produced from free chlorine (Jensen et al. 1985; Singer 1992; Symons et al. 1998).

2.7 Chlorine Dioxide

Chlorine dioxide is a powerful oxidant originally used by industries as a bleaching agent and disinfectant. Chlorine dioxide was first used for drinking water treatment in 1944 at the Niagara Falls, New York Water Treatment Plant. Currently, the major use of chlorine dioxide is as a pre-oxidant to control tastes and odors and to reduce THM formation in finished water (DeMers and Renner 1992).

2.7.1 Description of Chemistry

Chlorine dioxide (ClO₂) is a neutral compound of chlorine in the +IV oxidation state. ClO₂ is a yellow to red colored gas at temperatures above 11-12°C. Because ClO₂ does not hydrolyze in water, it exists as a dissolved gas as long as the pH of the water ranges from 2 to 10. In strongly alkaline solutions (pH greater than 9 or 10), however, formation rates of DBPs increase with increasing concentrations of chlorine dioxide. Chlorine dioxide is a volatile free radical that functions as an oxidant by way of a one-electron transfer mechanism in which it is reduced to chlorite (ClO₂⁻) (Hoehn et al. 1996; Noack and Doerr 1978). During drinking water treatment, chlorite is the predominant reaction byproduct, with 50 to 70 percent of the reacted chlorine dioxide being converted to chlorite and 30 percent to chlorate (ClO₃⁻) or chloride (Cl⁻) depending on the secondary disinfectant.

Although chlorine dioxide can be produced from sodium chlorate (NaClO₃), for most potable water applications, chlorine dioxide is generated from sodium chlorite (NaClO₂). The proportion of chlorine dioxide relative to impurities, including chlorite, chlorate, or free chlorine, is important when chlorine dioxide is applied to drinking water (Aieta and Berg 1986). Although a significant amount of chlorite ion can appear in drinking water from the application and subsequent reduction of chlorine dioxide, both precursor chlorite and chlorate ions can be constituent contaminants in generated solutions. EPA recommends that systems limit the formation of chlorite and chlorate by maintaining high generator purity (i.e., more than 95-percent efficiency) and limiting excess chlorine to no more than 5 percent of the applied dose of chlorine dioxide. Two feed chemical combinations that generate chlorine dioxide yield in excess of 95 percent are chlorine-sodium chlorite and acid-sodium hypochlorite-sodium chlorite.

Several feed chemical combinations that are used in the water industry are described below.

Acid–Chlorite Solution. Chlorine dioxide can be generated by acidification of a sodium chlorite solution, usually with hydrochloric acid, and several stoichiometric reactions have been reported for such processes (Gordon et al. 1972). When catalyzed by the presence of chloride ions, acid activation of sodium chlorite has a maximum possible yield of 80 percent of the quantity of chlorine dioxide that could be produced from a reaction of the same amount of sodium chlorite with chlorine (Petochelli 1995). The reaction is relatively slow, and production rates using this

method are practically limited to about 25 to 30 pounds per day, due to the exothermic nature of the reactions.

Chlorine Solution–Chlorite Solution. Chlorite ions (from dissolved sodium chlorite) will react in aqueous solutions with chlorine or hypochlorous acid to form chlorine dioxide. Two moles of chlorite ions will theoretically react with one mole of chlorine to produce two moles of chlorine dioxide. To fully utilize the sodium chlorite solution, excess chlorine is often used, reducing the pH and driving the reaction further toward completion. The reaction is faster than the acid–chlorite solution method, but much slower than the other commercial methods described in the following discussion. Chlorine dioxide production by this method is limited to about 1,000 pounds per day.

Chlorine Gas–Chlorite Solution. Sodium chlorite solution can be "vaporized" and reacted in a vacuum with molecular gaseous chlorine. This process uses concentrated reactants and is much more rapid than chlorine solution–chlorite solution methods (Petochelli 1995). If the chlorine and chlorite ions react stoichiometrically, the resulting pH is close to 7. Production rates are virtually unlimited, and some systems have reported producing more than 60,000 pounds per day.

Chlorine Gas–Solid Chlorite. This process reacts dilute, humidified chlorine gas with specially processed solid sodium chlorite contained in sealed reactor cartridges. The reaction is rapid and produces high-purity chlorine dioxide gas inherently free of chlorine and chlorate ions because these ions do not carry into the gas phase. Using multiple cartridges in series ensures an excess of sodium chlorite; thus, all chlorine is reacted and the chlorine dioxide produced is chlorine-free. Because the chlorine dioxide production rate is solely a function of the chlorine gas feed rate, generators that use chlorine gas–solid chlorite technology are capable of infinite turndown (i.e., the chlorine dioxide production rate can be adjusted without requiring recalibration between settings) (Petochelli 1995; Hoehn and Rosenblatt 1996). Chlorine gas–solid chlorite solution method production capacities are limited to 2,000 pounds per day.

In addition to the commercial processes discussed previously, other potential methods for generating chlorine dioxide include electrolysis of a sodium chlorite solution (with or without the use of membranes to purify the chlorine dioxide product), irradiation of dilute sodium chlorite solution with UV light, and reduction of sodium chlorate with concentrated sulphuric acid and 50 percent hydrogen peroxide.

2.7.2 Use and Distribution

Chlorine dioxide is almost never used commercially as a gas because it cannot be safely compressed and shipped. For potable water treatment process, it is predominantly generated in aqueous solutions. Because of the volatile nature of the gas, chlorine dioxide works extremely well in plug flow reactors, such as pipe lines. It can be easily removed from dilute aqueous solution by aerated turbulence, such as in a rapid mix tank or aerated cascade. For post-disinfection, chlorine dioxide can be added before clearwells or transfer pipelines.

An estimated 700 to 900 U.S. drinking water systems use chlorine dioxide, largely to oxidize iron and manganese, control taste and odor, and reduce THM levels (Hoehn et al. 1992). Some systems are looking to the higher disinfection efficacy of chlorine dioxide to decrease contact time needed for

Cryptosporidium control. Nineteen plants (3.7 percent) that participated in the ICR reported using chlorine dioxide for at least nine of the last 12 months of the ICR collection period (USEPA 2000i).

2.7.3 Advantages and Disadvantages

The following list highlights selected advantages and disadvantages of using chlorine dioxide to disinfect drinking water (Masschelein 1992; DeMers and Renner 1992; Gallagher et al. 1994).

- Advantages
 - More effective than chlorine and chloramines for inactivation of viruses (with longer contact times), *Cryptosporidium*, and *Giardia* (with shorter contact times).
 - Oxidizes iron, manganese, and sulfides.
 - Provides taste, odor, and color control.
 - Under proper generation conditions (i.e., no excess chlorine), TTHM is not formed.
 - Biocidal properties are not influenced by pH.
- Disadvantages
 - Incomplete generation of chlorine dioxide leaves unreacted chlorite and chlorate.
 - Generator inefficiency and optimization difficulty can result in excess chlorine feed at the application point, leading to formation of halogenated organic DBPs.
 - Costs are a concern: training, sampling, and laboratory testing for chlorite and chlorate are expensive; in many cases equipment must be rented; and the cost of the sodium chlorite is high.
 - Measuring a chlorine dioxide residual for determining disinfection credit is difficult.
 - Chlorine dioxide gas is explosive, so it must be generated on-site and requires careful handling.
 - Chlorine dioxide decomposes in sunlight.
 - Chlorine dioxide can lead to production of noxious odors for customers in some systems if chlorine dioxide is present at the tap.
 - It is difficult to maintain a chlorine dioxide residual in the distribution system.

Because of the wide variation in system size, water quality, and resulting dosages of chlorine dioxide applied, not all of these advantages and disadvantages apply to all systems.

2.7.4 Dose Ranges

Before chlorine dioxide, or any disinfectant, is selected as a primary disinfectant, an oxidant demand study must be completed. Ideally, this study should consider the seasonal variations in water quality, temperature, and application points. EPA recommends that the combined concentrations of chlorine dioxide, chlorate, and chlorite not exceed 1.0 mg/L in finished water. This means that if the desired oxidant dosage is greater than about 1.4 mg/L, the chlorite/chlorate byproduct concentrations would already be at the maximum level (based on a roughly 70 percent conversion rate); therefore, chlorine dioxide would not be acceptable as a disinfectant. Higher doses are possible if the plant uses ferrous ion treatment to remove chlorite or reduced sulfur compounds (Singer and Reckhow 1999). The range of doses includes both primary and secondary disinfection, although chlorine dioxide typically is

used for primary disinfection. Note that these ranges represent the extremes; normal doses fall within these ranges.

Exhibit 2.11 presents chlorine dioxide doses (average, minimum, and maximum of all plantmonths where data was reported for nine of the last 12 months of the ICR collection period) for surface water plants using chlorine dioxide. A number of surface water plants using chlorine dioxide (58 percent) had average chlorine dioxide doses between 1.0 and 1.5 mg/L as ClO_2 .



Exhibit 2.11 Chlorine Dioxide Doses (Plant Minimum, Mean, and Maximum)

Note:Open circles represent plant means and lines represent minimum and maximum values.Source:ICR AUX2 Database (USEPA 2000i).Query:Screened SW Plant-Mean CLX Doses (w AUX2). See Appendix B for details.

2.7.5 Byproducts

Small amounts of chlorine are often present when chlorine dioxide is used, so halogenated organic DBPs are often detected in small quantities. However, the application of chlorine-free chlorine dioxide does not form THMs and produces only a small amount of TOX (Werdehoff and Singer 1987) and other halogenated-substituted compounds at very low concentrations (Richardson 1998). Primarily, however, the application of chlorine dioxide to water results in oxidation/reduction reactions that form two inorganic DBPs: chlorite and chlorate (Rav-Acha et al. 1984; Werdehoff and Singer 1987). Chlorite and chlorate frequently are found as contaminants in chlorine dioxide feed streams, and chlorite is formed as a byproduct from disinfection with chlorine dioxide (Griese et al. 1991). However, chlorine dioxide

does not generate bromine-substituted byproducts to the same extent as ozone in bromide-containing waters. Chlorite in drinking water results from two parts of the chlorine dioxide disinfection process:

- Unreacted chlorite from the chlorine dioxide generation process
- Reduction of chlorine dioxide when it reacts with organic matter in water

Incomplete reaction or non-stoichiometric addition of the sodium chlorite and chlorine reactants can result in unreacted chlorite or, more likely, chlorate in the chlorine dioxide feed stream. Upon application to water, chlorine dioxide is fairly unstable and rapidly dissociates into chlorite and chlorate at pHs above 10. This occurs only to a limited extent where residuals of chlorine dioxide are greater than 1 percent. Chlorite ions are the primary product of chlorine dioxide reduction, but the percentage of chlorite and chlorate present is influenced by pH and sunlight, as well as the efficiency of the chlorine dioxide generator.

The quantity of chlorate produced during chlorine dioxide generation increases with excess chlorine addition. Similarly, low pH can increase the quantity of chlorate during chlorine dioxide generation. The predominant source of chlorate ions in finished water, however, results from the oxidation of chlorite (from the applied chlorine dioxide) by free available chlorine used as a final distribution system disinfectant (Gallagher et al. 1994). Consequently, chlorate concentrations are expected to increase with increasing contact time in water containing chlorite and chlorine. Once formed, chlorate is stable in finished drinking water.

2.8 Ozonation

Ozone (O_3) is used in water treatment for disinfection and oxidation. Early application of ozone was primarily for non-disinfection purposes, such as color removal or taste and odor control. Since implementation of the SWTR, Stage 1 DBPR, and IESWTR, ozone usage for disinfection has increased. Ozone is a powerful oxidant capable of oxidizing many organic and inorganic compounds in water.

Ozone was first used for drinking water treatment in 1893 in the Netherlands. While used frequently in Europe to disinfect drinking water, ozonation technology was slow to transfer to the United States. In 1991, approximately 40 water treatment plants serving more than 10,000 people in the United States used ozone (Langlais et al. 1991). This number had grown to 201 by 1997 (Rice and Dimitrou 1997). Most of these facilities are small: 90 plants treat fewer than 1 million gallons per day (mgd) and only six exceeded 100 mgd as of May 1997. ICR data show that 14 large surface water plants reported using ozone for at least nine of the last 12 months of the ICR collection period (USEPA 2000d). Another source cites that as of January 2000, 275 plants were using ozone, with another 16 plants expected to come on line in the next year (Rice 2000). Many of these plants are using ozone for purposes besides disinfection. Rice also estimates that many very small systems in California, many of which may be non-community systems, use ozone as a disinfectant in their storage tanks.

2.8.1 Description of Chemistry

A gas at room temperature, ozone is highly corrosive and toxic. The gas is colorless with a pungent odor readily detectable at concentrations as low as 0.01 to 0.05 parts per million (ppm), which is below concentrations that would cause a health problem.

Ozone decomposes spontaneously in water by a complex reaction involving the generation of oxygen and hydroxyl free radicals. Hydroxyl radicals are among the most reactive oxidizing agents in water due to their unpaired electrons (Hoigne and Bader 1983a; Hoigne and Bader 1983b; Glaze et al. 1987). Ozone reacts in two modes in aqueous solutions: direct oxidation of compounds by aqueous ozone $(O_{3(aq)})$ and oxidation of compounds by hydroxyl radicals (OH⁻) produced during the spontaneous decomposition of ozone (Hoigne and Bader 1977).

2.8.2 Use and Distribution

Ozone is used in drinking water treatment for various purposes.

- Disinfection to control Giardia, Cryptosporidium, and other microbes
- Inorganic pollutant oxidation, including iron, manganese, and sulfide
- Organic micropollutant oxidation, including taste and odor compounds, phenolic pollutants, and pesticides
- Organic macropollutant oxidation, including color removal, increasing the biodegradability of organic compounds, THM and TOX precursor control, and destruction of chlorine demand
- Improvement of coagulation and filtration

Ozone is unstable, so it must be generated at the point of application. It is generally formed by combining an oxygen atom with an oxygen molecule (O_2) . This reaction is endothermic and requires considerable energy. Ozone can be produced several ways, including by irradiating an oxygen-containing gas with electrolytic reactions, ultraviolet light, or high-energy radiation. These are all processes that produce free oxygen radicals from electron or photon energy input.

One method, corona discharge, predominates in the water industry. Corona discharge, also known as silent electrical discharge, consists of passing an oxygen-containing gas through two electrodes separated by a dielectric and an air gap. A voltage is applied to the electrodes, causing an electron flow across the air gap. These electrons provide the energy to dissociate the oxygen molecules, leading to the formation of ozone in the gas stream. Then, the ozone is transferred into the water, with any non-transferred ozone being converted to oxygen before being released into the atmosphere. Therefore, no chemical inputs are needed.

For most applications, ozone is applied either to the raw water or after some type of clarification process. Turbidity and ozone demand (the amount of ozone required to oxidize all the constituents in the water) influence the way ozone is used in the treatment process. By moving the ozonation process further downstream, the ozone demand and production of oxidation byproducts are reduced. The advantage of placing ozone ahead of filtration is that biodegradable organics produced during ozonation can be

removed in the filters if they are allowed to operate biologically (i.e., with no disinfectant residual). Bacteria living in the biofilm growing on filters can break down and feed on the oxidized NOM. Biological filtration is often necessary for waters that have high levels of NOM.

2.8.3 Advantages and Disadvantages

The following list highlights selected advantages and disadvantages of using ozone to disinfect drinking water (Masschelein 1992).

- Advantages
 - Ozone is more effective than chlorine, chloramines, and chlorine dioxide for inactivation of viruses, *Cryptosporidium*, and *Giardia*.
 - Ozone oxidizes iron, manganese, and sulfides.
 - Ozone can sometimes enhance the clarification process and turbidity removal.
 - Ozone improves color, taste, and odors.
 - Ozone requires a very short contact time.
 - Halogenated organic DBPs are not formed by ozonation if bromide is absent.
 - Enhances the biodegradability of natural and synthetic organic compounds and destroys many organic compounds.
 - Since most of the oxidant demand is satisfied by ozone, the amount of chlorine needed for secondary disinfection is generally much lower.
- Disadvantages
 - DBPs formed include bromate and bromine-substituted DBPs (when bromide is present), as well as aldehydes and ketones (if there is incomplete oxidation of some organic compounds and acids).
 - The initial cost of ozonation equipment is high.
 - The generation of ozone is energy-intensive and must be generated on site.
 - Ozone is highly corrosive and toxic.
 - Ozone decays rapidly at high pH and warm temperatures.
 - Ozone provides no residual and therefore a secondary disinfectant such as chlorine may be needed for the distribution system.
 - Ozone plants require a higher level of maintenance and operator skill.
 - Low disinfection efficiency at low water temperatures.
 - Ozone forms biodegradable oxygenated byproducts that can lead to regrowth of biological material in the distribution system.
 - Storage of all the necessary oxygen feed gas generators, the ozone generation equipment, the cooling equipment, and the off gas collection and destruction equipment, is likely to take up more space than a typical liquid storage and feed facility

Because of the wide variation in system size, water quality, and ozonation dosages applied, not all of these advantages and disadvantages apply to all systems.

2.8.4 Dose Ranges

Engineering design manuals and published articles were used in developing an ozone dose range for the guideline used to review PWSs' ICR initial sampling plans. This range of doses is for primary disinfection only. Note that these ranges represent extremes, and normal values fall between these values. Ozone plants participating in the ICR also reported the doses of ozone they used. Exhibit 2.12 presents ozone doses (average, minimum, and maximum of all plant-months where data was reported for nine of the last 12 months of the ICR collection period) for surface water plants using ozone. Approximately 86 percent of surface water plants using ozone had an average ozone dose below 3.0 mg/L as O₃.



Exhibit 2.12 Ozone Doses (Plant Minimum, Mean, and Maximum)

Note:Open circles represent plant means and lines represent minimum and maximum values.Source:ICR AUX2 Database (USEPA 2000i).Query:Screened SW Plant-Mean O3 Doses (w AUX2).See Appendix B for details.

2.8.5 Byproducts

A variety of organic and inorganic byproducts have been observed following ozonation of water. Ozone can react with bromide naturally present in water to form bromate and bromine-substituted DBPs. The primary factors affecting the speciation and concentrations of bromine-substituted byproducts are pH and the ratios of ozone-to-bromide and total organic carbon-to-bromide (Singer 1992). Refer to Chapter 15 of the *Information Collection Rule Data Analysis* document (McGuire et al. 2002) for data on source water bromide concentrations for plants using ozone.

The principal benefit of using ozone to control THM formation is that ozone allows free chlorine to be applied at lower doses later in the treatment process, after some of the TTHM and HAA5 precursors have been removed, thereby reducing the potential for TTHM and HAA5 formation. However, application of a secondary disinfectant following ozonation requires special consideration for potential interaction between disinfectants. For example, chloral hydrate formation has been observed to increase when chlorine is used as a secondary disinfectant after ozone (McKnight and Reckhow 1992; Logsdon et al. 1992). One byproduct of ozonation, acetaldehyde, is a known precursor of chloral hydrate. Enhancement of chloral hydrate formation has not been observed when monochloramine is applied as the secondary disinfectant, or if biologically active filtration is used following ozonation and prior to chlorination (Singer 1992). Chloropicrin formation from free chlorine also appears to be enhanced by pre-ozonation (Hoigne and Bader 1988).

Organic oxidation byproducts, including aldehydes, ketones, aldo-acids, ketoacids, carboxylic acids, and assimilable organic carbon (AOC) can be formed upon ozonation of water containing a high level of NOM. The primary aldehydes that have been detected are formaldehyde, acetaldehyde, glyoxal, and methyl glyoxal (Glaze et al. 1991). The ICR data provided occurrence information on these substances along with propanal, pentanal, and butanal. Total aldehyde concentration in drinking water disinfected with ozone ranges from less than 5 to $300 \mu g/L$, depending on the TOC concentration and the applied ozone-to-organic-carbon ratio (Van Hoof et al. 1985; Yamada and Somiya 1989; Glaze et al. 1989; Krasner et al. 1989; Glaze et al. 1991; LeLacheur et al. 1991).

Ozonation of water containing bromide can produce hypobromous acid and hypobromite, which, in turn, can contribute to the formation of bromine-substituted byproducts, the brominated analogues of the chlorinated DBPs. These bromine-substituted byproducts include: bromoform; the bromine-substituted acetic acids, acetonitriles, and aldo-acids; bromopicrin; and cyanogen bromide. Bromoform has been found to form when water is ozonated (McGuire et al. 1990). Cyanogen bromide has been found to form when water is ozonated (McGuire et al. 1990). An ICR plant with the median ozone dose of 1.84 mg/L had influent bromide levels of 0.133 mg/L and finished water bromate levels of 3.1 μ g/L. Dibromoacetic acid levels of 3.5 μ g/L were also detected, but all other brominated DBPs were below their minimum reporting levels.

Ozone can react with the hypobromite ion to form bromate (Siddiqui and Amy 1993; Krasner et al. 1993; Amy et al. 1997). Bromate formation is affected by NOM, pH, bromide ion concentrations, inorganic carbon, and ozone dose. Decreasing pH (8.5–6.5) generally decreases bromate formation because the equilibrium is shifted to hypobromous acid, which does not form bromate. Lower pH, however, enhances the formation of bromine-substituted DBPs formed by the reaction of hypobromous acid and NOM. Higher bromide ion concentrations and high inorganic carbon concentrations have been noted with increased bromate ion formations (Amy et al. 1997).

The amount of bromide incorporated into the detected DBPs accounts for only one-third of the total source water bromide concentration. This indicates that other bromine-substituted DBPs exist that are not yet identified (McGuire et al. 1989; AWWARF 1991).

3. National DBP Occurrence: Pre-Stage 1 Baselines

This chapter summarizes the data used to assess disinfectant residuals and disinfection byproduct (DBP) occurrence in public drinking water supplies. The Information Collection Rule (ICR) data for large surface water plants and other data for medium sized plants was collected prior to compliance deadline for the Stage 1 DBPR (2002 for medium and large surface water systems and 2004 for small surface water systems and all ground water systems). This data is used in this chapter to investigate DBP occurrence before the implementation of Stage 1 (pre-Stage 1). Chapter 4 provides a prediction of post-Stage 1 DBP occurrence.

The main source of DBP data for this analysis is the ICR, which authorized EPA to require the collection of occurrence and treatment information from disinfecting water systems serving 100,000 or more people. The ICR data described in this chapter are from the AUX1 database, CD version 5.0 (USEPA 2000d). Information about medium (10,000 to 99,999 people served) and small (fewer than 10,000 people served) systems comes from the National Rural Water Association (NRWA) Survey (USEPA 2001g), ICR Supplemental Surveys, the Water Utility Database (WATER:\STATS), and data provided by several States. Because the data available for medium and small systems are not as extensive as the ICR data, the majority of this chapter is a presentation of ICR data for individual water quality parameters and DBPs for large systems. EPA found that there are significant similarities between large systems and medium and small systems with regard to source water quality (affecting DBP formation) and use of treatment technologies. Because of these similarities, EPA expects that small and medium systems would find DBP distribution system levels similar to those found in large systems following compliance with the Stage 1 DBPR requirements.

The organization of the remainder of this chapter is as follows:

- Section 3.1 presents large system occurrence data provided through the ICR for DBP precursors and other parameters that affect DBP formation, disinfectant residuals, and DBPs.
- Section 3.2 presents medium and small system occurrence data derived from sources other than the ICR.
- Section 3.3 evaluates co-occurrence among certain ICR water quality parameters and the relationships of these interactions.
- Section 3.4 evaluates regional occurrence trends for some DBP precursors.

Data analyses in this chapter are supported by two appendices. Appendix A provides summary information on the individual species of trihalomethanes (THMs) and five haloacetic acids (HAAs). Appendix B provides the Microsoft AccessTM query language that was used to extract data from the ICR AUX1 database. There are uncertainties in using the ICR to characterize the pre-Stage 1 baseline. See Chapter 3 of the Stage 2 Economic Analysis for a detailed discussion of these uncertainties.

3.1 ICR Data

Sections 3.1.1 through 3.1.3 present the ICR summary data for large systems with a description of analyte characteristics as follows:

Section 3.1.1	DBP Precursors
Section 3.1.2	Disinfectant Residuals
Section 3.1.3	DBPs

Summary statistics in this section are generally for "plant-mean" data—that is, for each plant, the mean concentration of an analyte was calculated using all reported data during the last 12 months of the ICR collection period. Summary statistics were then generated based on the distribution of all plant-means. See section 1.4.8 for a detailed description of the methodology used to generate ICR data summaries in this section.

3.1.1 DBP Precursors

This section summarizes plant-mean data for water quality parameters that can affect the formation of DBPs. These water quality parameters are total organic carbon (TOC), temperature, bromide, and UV_{254} absorbance. Summary statistics shown in Exhibit 3.1 are calculated using the last 12 months of the ICR collection period for plants that have at least nine months of data for each parameter. Values below the minimum reporting level (MRL) were converted to zero to calculate plant-means. Exhibits 3.2 through 3.5 compare the cumulative distributions of plant-mean values for ground and surface water plants. Exhibit 3.6 characterizes plant-level variability by showing the distribution of the maximum value minus the minimum value at each plant for each water quality parameter.

All data in this section represent samples collected from the influent water sampling location. Although the ICR required samples to be collected throughout the treatment plant, the influent water sampling point was selected to illustrate parameters of the influent water quality matrix that ICR systems consider during treatment. Although the water quality characteristics that directly affect DBP formation are present at the point of disinfectant addition, this section focuses on influent characteristics with the understanding that treatment will change the parameters. Observations regarding the data follow the exhibits.

Source Water	Number of Plants	Mean of Plant-Means	Median of Plant-Means	90th Percentile of Plant-Means	Range of Plant-Means ³		
Total Organic Carbon (mg/L as Carbon [C])							
Surface	307	3.14	2.71	5.29	0.0 - 21.4		
Ground	103	1.46	0.19	3.36	0.0 - 16.1		
All ¹	423	2.71	2.45	5.10	0.0 - 21.4		
Temperature	e (degrees C	elsius)					
Surface	334	16.0	16.1	20.7	3.7 - 27.7		
Ground	121	19.9	20.1	26.3	9.5 - 30.5		
All ¹	473	17.1	17.0	24.5	3.7 - 30.5		
Bromide (mg/L) ²							
Surface	320	0.055	0.027	0.115	0.000 - 1.325		
Ground	118	0.103	0.066	0.190	0.000 - 1.325		
All ¹	449	0.068	0.036	0.151	0.000 - 1.325		
UV-254 Absorbance (cm ⁻¹)							
Surface	306	0.098	0.079	0.176	0.000 - 0.880		
Ground	104	0.062	0.009	0.266	0.000 - 0.606		
All ¹	424	0.091	0.069	0.180	0.000 - 0.880		

Exhibit 3.1 Summary of Influent Water Quality Parameter ICR Data for All Large Plants

Notes: ¹"All" plants include those with surface, ground, blended, mixed, or purchased source water types, so "All" does not equal the sum of surface and ground.

²Plant 402 was removed from the analysis for bromide. Its plant-mean bromide value of 2.36 mg/L was calculated based on one month of bromide levels of 28 mg/L. All the other values for that plant in the last 12 months of the ICR were below 0.1 mg/L. The 28 mg/L value is most likely a reporting error as laboratories often report bromide values in μ g/L rather than mg/L, and this value may not have been converted to mg/L.

³Values below the minimum reporting level (MRL) were converted to zero in order to calculate plantmeans.

Source: ICR AUX1 database (USEPA 2000d).

Queries: Screened TOC INF, Screened TEMP INF, Screened BROMIDE INF, and Screened UV_254 INF. See Appendix B for query language.




Source: ICR AUX1 database (USEPA 2000d). Query: Screened TOC INF. See Appendix B for query language.



Exhibit 3.3 Cumulative Distribution of Plant-Mean Water Temperature of Influent Samples Based on ICR Data for Large Surface and Ground Water Plants (degrees Celsius)

Source: ICR AUX1 database (USEPA 2000d). Query: Screened TEMP INF. See Appendix B for query language.

Exhibit 3.4 Cumulative Distribution of Plant-Mean Bromide Concentrations of Influent Samples Based on ICR Data for Large Surface and Ground Water Plants (mg/L)



Note: Plant 402 was removed from the analysis for bromide. Its plant mean bromide value of 2.36 mg/L was calculated based on one month of bromide levels of 28 mg/L. All the other values for that plant in the last 12 months of the ICR were below 0.1 mg/L. The 28 mg/L value is most likely a reporting error as laboratories often report bromide values in μ g/L rather than mg/L, and this value may not have been converted to mg/L.

Query: Screened BROMIDE INF. See Appendix B for query language.

Source: ICR AUX1 database (USEPA 2000d).



Exhibit 3.5 Cumulative Distribution of Plant-Mean UV₂₅₄ Absorbance of Influent Samples Based on ICR Data for Large Surface and Ground Water Plants (cm⁻¹)

Source: ICR AUX1 database (USEPA 2000d). Query: Screened UV_254 INF. See Appendix B for query language.

TOC is a measure of the organic carbon content of water. This organic content contributes to the formation of DBPs. In unpolluted source water, humic and fulvic acids from the decay of vegetation are the major constituents of TOC; in polluted water, pesticides and other manmade chemicals may be constituents of TOC as well (Amirtharajah and O'Melia 1990). Researchers have found that TOC can be a good indicator of the amount of THMs and other DBPs that may form as a result of chemical disinfection (Singer and Chang 1989). Correlations between TOC and DBPs are presented in section 3.3.

Mean TOC concentrations for ICR influent samples at surface water plants are more than double the mean influent TOC concentrations in ground water plants. Approximately 42 percent of ground water plants have mean TOC concentrations less than or equal to 0.1 mg/L as C, whereas less than 1 percent of surface water plants have mean TOC concentrations less than 0.1 mg/L as C. However, as shown in the cumulative distribution of TOC concentrations in Exhibit 3.2, TOC concentrations in the upper 95th percentile are higher for ground water than surface water plants.

Temperature can affect many aspects of water chemistry and treatment. Generally, as temperature increases so do chemical reaction rates which increase the amount of DBPs formed (specifically trihalomethanes) and the efficiency of chlorine disinfection. Temperature also affects the solubility of different substances in water (including calcium carbonate, which can change pH, alkalinity, and hardness).

Temperature fluctuates much more in surface water than in ground water. Plant-mean temperature can be lower in surface water than in ground water, since the surface water is directly exposed to the air and ground water sources are insulated by the ground. The mean of plant-mean temperature level for surface water plants is 16.0° C, while the mean of plant-mean temperature levels for ground water plants is 19.9° C.

Bromide can be present as a result of salt water intrusion into an aquifer, human activities such as pesticide and road salt application, and dissolution of minerals in geologic formations (Siddiqui et al. 1995). The presence of bromide in source water can affect the type and amount of DBPs formed, shifting the distribution of DBPs generated to the more brominated species (Krasner et al. 1989). In addition, bromide can react with strong oxidants, such as ozone or chlorine dioxide, to form bromate, another byproduct of concern.

Bromide concentrations are typically higher in ground water than in surface water sources, in part because ground water has long contact time with geologic formations that can be sources of bromide. This is reflected by the ICR results—mean bromide concentration was 0.103 mg/L for ground water plants compared to 0.055 mg/L for surface water plants. Peak values, however, were identical for surface and ground water plants, calculated at 1.33 mg/L. Bromide levels can be impacted by seasonal climate conditions. Bromide levels tend to be higher during drought periods because of the concentration of ions in a smaller volume of water. Bromide occurrence also varies regionally. Section 3.4 shows analysis of regional trends for influent bromide. See Chapter 14 of the *Information Collection Rule Data Analysis* document (McGuire et al. 2002) for additional information regarding bromide occurrence.

The absorbance of UV radiation at a wavelength of 254 nanometers correlates with the amount of unsaturated organic compounds, particularly dissolved matter such as humic substances, in the water (USEPA 1999a). UV₂₅₄ absorbance can be used as an alternative to measuring TOC or dissolved organic carbon (DOC) as an indicator of DBP precursors in raw water. Exhibits 3.2 and 3.5 show that the distributions of TOC and UV₂₅₄ absorbance for ground and surface water plants follow very similar trends, with surface water plants generally showing higher plant-mean values (except in the upper 5th percentile).

Exhibit 3.6 provides statistics for the difference between the highest and lowest monthly values on a plant-by-plant basis (as reported during the last 12 months of the ICR) for TOC, temperature, bromide, and UV_{254} . On average, the difference between the highest and lowest values for TOC, temperature, and UV_{254} is roughly three to four times greater in plants using surface waters than in plants using ground waters. The difference between the highest and lowest bromide value is also greater, on average, for surface water plants compared to ground water plants, but not by as much. These general trends are consistent across the range of percentiles. These findings are consistent with general observations that ground water varies less over a year than surface water.

Exhibit 3.6 Cumulative Distribution of Differences Between Highest and Lowest Monthly Parameter Values for Influent Water Sample Location Based on ICR Data for All Large Plants

Source Water	Number of Plants	Mean	25th Percentile	50th Percentile	75th Percentile	90th Percentile	95th Percentile		
Total Organi	c Carbon (m	g/L as Ca	rbon [C])						
Surface	307	2.26	0.95	1.55	2.70	4.10	5.60		
Ground	103	1.01	0.00	0.80	1.30	1.95	2.75		
All ¹	423	1.93	0.80	1.30	2.30	3.75	5.35		
Temperature (degrees Celsius)									
Surface	334	17.0	13.2	18.0	21.0	23.0	24.5		
Ground	121	4.3	2.0	3.8	5.2	8.2	12.0		
All ¹	473	13.5	6.9	14.3	19.8	22.0	24.0		
Bromide (mg	g/L) ²								
Surface	320	0.078	0.023	0.040	0.091	0.160	0.260		
Ground	118	0.060	0.024	0.043	0.082	0.110	0.210		
All ¹	449	0.073	0.024	0.041	0.090	0.150	0.260		
UV-254 Abso	UV-254 Absorbance (cm ⁻¹)								
Surface	306	0.121	0.034	0.070	0.134	0.302	0.448		
Ground	104	0.033	0.000	0.015	0.036	0.085	0.127		
All ¹	424	0.106	0.023	0.049	0.120	0.280	0.412		

Notes: ¹"All" plants include those with surface, ground, blended, mixed, or purchased source water types, so "All" does not equal the sum of surface and ground.

²Plant 402 was removed from the analysis for bromide. Its plant mean bromide value of 2.36 mg/L was calculated based on one month of bromide levels of 28 mg/L. All the other values for that plant in the last 12 months of the ICR were below 0.1 mg/L. The 28 mg/L value is most likely a reporting error as laboratories often report bromide values in μ g/L rather than mg/L, and this value may not have been converted to mg/L.

Source: ICR AUX1 database (USEPA 2000d).

Queries: Screened TOC INF, Screened TEMP INF, Screened BROMIDE INF, and Screened UV_254 INF. See Appendix B for query language.

3.1.2 Disinfectant Residuals

This section summarizes residual concentrations for chlorine, chloramine, and chlorine dioxide in finished water (taken from the end of the treatment plant, before water enters the distribution system) and ozone residuals after the last contact chamber (see Chapter 2 for a discussion of disinfectant use and doses). Disinfectants were monitored monthly, although there are no ground water data for some of the disinfectant types. Summary statistics, calculated using the last 12 months of the ICR collection period for plants that have at least nine months of data for each parameter, are shown in Exhibit 3.7. General observations regarding the data follow Exhibit 3.7.

	Data Sample	Number of	Mean of	Median of	90th Percentile of	Range of	
Source	Location	Plants	Plant-Means	Plant-Means	Plant-Means	Plant-Means	
Free Chlorine Re	sidual (mg/L) ¹						
Surface	Finished	183	1.23	1.14	1.98	0.00-4.37	
Ground	Finished	33	1.13	1.04	2.06	0.17-2.61	
All ³	Finished	224	1.22	1.13	1.98	0.00-4.37	
Total Chlorine Re	esidual (mg/L)						
Surface - CL ₂ ¹	Finished	187	1.56	1.33	2.53	0.33-4.58	
Ground - CL ₂ ¹	Finished	37	1.45	1.17	3.25	0.17-3.73	
All ³ - CL ₂ ¹	Finished	232	1.55	1.33	2.58	0.17-4.58	
Surface - CLM ²	Finished	89	2.51	2.35	3.58	1.07-5.19	
Ground - CLM ²	Finished	14	3.07	3.23	4.57	1.33-4.62	
All ³ - CLM ²	Finished	105	2.58	2.46	3.66	1.07-5.19	
Chlorine Dioxide	Residual (mg/L)						
Surface	Finished	20	0.61	0.21	2.13	0.00-2.74	
Ozone Residual	Ozone Residual (mg/L)						
Surface	After Last Contact Chamber	13	0.08	0.06	0.13	0.01-0.21	

Exhibit 3.7 Summary of Disinfectant Residual ICR Data for All Large Plants

Notes:

¹ For plants using chlorine only.

² For plants using chlorine and chloramines or chloramines only.

³ "All" plants include those with surface, ground, blended, mixed, or purchased source water types.

Source: ICR AUX1 database (USEPA 2000d).

Queries: Screened EXFCLRES FIN, Screened EXTCLRES FIN, Screened EXCLXRES FIN, and Screened EXO3RES. See Appendix B for query language.

Excel File: ICR Disinfectant Residuals.xls

In water, chlorine exists as hypochlorous acid (HOCl) and hypochlorite (OCl⁻). Free chlorine is defined as the sum of the concentrations of HOCl and OCl⁻ measured as Cl₂. The Surface Water Treatment Rule (SWTR) sets minimum requirements for residual disinfectant concentration. For instance, the residual disinfectant concentration at the point of entry to the distribution system may not drop below 0.2 mg/L for more than four hours, although the regulations do not state that the disinfection concentration must be measured as free chlorine residual. The rule also sets CT (the product of contact time and disinfectant concentration) requirements for surface water systems (USEPA 1989a). For CT

calculation, plants must take all contact chambers into account. CT is used to achieve the inactivation of microorganisms, as required by the SWTR.

The mean of all plant-mean free chlorine residual concentrations were similar for surface water (1.23 mg/L) and ground water plants (1.13 mg/L), with the mean for all plants of approximately 1.22 mg/L. Although surface water plants exhibit a higher upper range value (4.37 mg/L), ground water plants have a slightly higher 90th percentile of plant means (2.06 mg/L).

Total chlorine is defined as the sum of free chlorine and combined chlorine (chloramine) concentrations, and is expressed in mg/L as Cl_2 . Total chlorine residuals for surface and ground water plants that use chloramines are higher, and the difference is statistically significant, than total chlorine residuals for surface and ground water plants that use only free chlorine. Higher total chlorine residual concentrations in chloramine systems may be due to organic material and DBP precursors and thus, higher chlorine demand in those systems. Also, the higher chlorine residuals in the chloraminated systems are due to the slower decay rate of chloramine compared to free chlorine. Higher chloramine levels can be maintained with a lower rate of total trihalomethane (TTHM) and HAA5 formation.

Only twenty surface water plants reported using chlorine dioxide for at least nine of the last 12 months of the ICR collection period. Although not in effect at the time of the ICR, the Stage 1 DBPR sets a daily maximum residual disinfectant level (MRDL) of 0.8 mg/L for chlorine dioxide based on sampling at the entry point to the distribution system (which can be interpreted in most cases to mean finished water). Average chlorine dioxide residuals range from 0 to 2.74, with four plants (or 20 percent) having mean residual concentrations greater than 0.8 mg/L.

Ozone (O_3) is a colorless gas that is unstable and decomposes rapidly, reacting with hydroxide ions (OH⁻) to form hydroxyl radicals and organic radicals. (Radicals are unstable molecules with unpaired electrons.) As part of ICR sampling, plants measured ozone residuals of the effluent of each ozone contact chamber. For this current analysis, only the ozone residual at the last contact chamber is presented to show the small potential for DBP formation outside the contact chambers. The plant-mean ozone residual concentrations in the last ozone contact chamber are very low, with an average of 0.08 mg/L. Averages ranged from 0.01 to 0.21 mg/L for the 13 surface water plants that submitted ICR data.

3.1.3 DBPs

Halogenated organic DBPs form as a result of reactions of free chlorine, bromide, or chloramines with naturally occurring organic matter. Studies show that some of these DBPs can cause adverse reproductive and development health effects and some forms of cancer (USEPA 2005a). Inorganic DBPs are also of concern, and are usually formed during reactions of chlorine dioxide with water and ozone with bromide.

A description of how distribution system DBP data are aggregated is provided below. Next, this section summarizes results for all halogenated DBPs measured during the ICR (see Exhibit 1.4 for a full list of DBPs measured during the ICR). The remainder of the section focuses on regulated DBPs (TTHM, HAA5, bromate, and chlorite). See section 1.4.8 for a detailed description of the methodology used to generate DBP results using ICR data.

Chapter 4 builds on this section by providing additional analyses of TTHM and HAA5 occurrence (e.g., spatial and temporal variation in the distribution system (DS)) for only those plants in compliance with the Stage 1 DBPR.

Aggregation of DBP Data

As explained in section 1.4.1, each ICR plant collected samples from a single finished water location and from four distribution system sample locations (DSE, AVG1, AVG2, DS Maximum) for the ICR. DBP data in this section and in Chapter 4 are aggregated into the following data types for analyses:

- <u>Finished Water</u> means a sample taken from the end of the treatment plant, before water enters the distribution system. The *plant-mean* finished water concentration is the average of the last four quarters of finished water data for that plant.
- <u>DS Average (or RAA)</u> is the calculated average of four distribution system samples (DSE, AVG 1, AVG 2, and DS Maximum). The *plant-mean* DS Average concentration is the average of the last four quarters of calculated DS Average data for that plant. The plant-mean DS Average concentration is equivalent to the running annual average (RAA) concentration for that year.
- <u>Single Highest</u> is the highest concentration of the four distribution system samples collected by a plant in the last four quarters of the ICR (16 possible values). This value may represent any of the four distribution system locations—DSE, AVG1, AVG2, or DS Maximum.
- <u>Locational Running Annual Average (LRAA)</u> is the average of four quarters of data from a single distribution system location (DSE, AVG1, AVG2, and DS Maximum). For example, the LRAA for the DSE location would be the average of the last four quarters of data collected from that location. The *highest* LRAA is the maximum of the four (DSE, AVG1, AVG2, and DS Maximum) calculated LRAAs. Since the LRAA covers one year's worth of data, it already represents a plant-mean value.
- <u>Max-Min</u> is the highest concentration of the four distribution system samples collected by a plant during the last four quarters of the ICR (16 possible values) *minus* the lowest concentration of the four distribution system samples reported during the last four quarters of the ICR. In other words, Max-Min is a single value that represents the difference between the maximum and minimum concentrations from all four distribution system samples collected during the last four quarters of the ICR.

3.1.3.1 All Measured Halogenated DBPs

Exhibit 3.8 summarizes DS Average results for all halogenated DBPs measured under the ICR. As can be seen from the measured concentrations for all plants, TTHMs and HAA5 comprise approximately 50 percent of the measured total organic halides (TOX), whereas the other measured organic halides (HAN4, CH, CP, DCP, and TCP¹) represent approximately 7 percent of the TOX concentration.

¹HAN4 stands for Haloacetonitriles (the sum of dichloroacetonitrile, trichloroacetonitrile, bromochloroacetonitrile, and dibromoacetonitrile). CH stands for chloral hydrate. CP stands for chloropicrin. DCP stands for dichloropropanone. TCP stands for trichloropropanone.

Exhibit 3.8 Summary of Halogenated DBP Data Measured During the ICR, Single Highest (Parameter Occurrence Values in µg/L) for All Large Plants

		Number of	Mean of Plant	Median of Plant-	90th Percentile	Range of
Source	Parameter	Plants	Means	Means	of Plant-Means	Plant-Means
	ттнм	213	68.68	63.90	118.70	0-177
	HAA5	213	24.60	20.85	45.78	0-104
	HAN4	209	3.79	3.20	7.62	0-17.5
Surface	СН	208	4.82	4.36	9.91	0-18.7
Sunace	СР	208	0.34	0.19	0.94	0-2.4
	DCP	209	0.54	0.37	1.35	0-2.8
	ТСР	209	1.50	1.23	0.00	0-6.4
	тох	213	144.19	138.16	241.25	0-305
	ТТНМ	82	15.36	6.79	36.95	0-123
	HAA5	82	6.35	0.33	18.83	0-97
	HAN4	80	2.22	0.75	6.01	0-14.8
	СН	80	0.59	0.03	2.18	0-5.5
Ground	СР	79	0.03	0.00	0.13	0-0.6
	DCP	80	0.19	0.00	0.91	0-2.0
	ТСР	80	0.07	0.00	0.00	0-1.2
	тох	81	54.40	7.88	160.00	0-482
	ТТНМ	304	25.78	23.13	53.83	0-119
	HAA5	304	19.40	16.20	41.45	0-104
	HAN4	305	3.37	2.69	7.32	0-17.5
A 11	СН	304	3.63	2.76	8.56	0-18.7
All	СР	303	0.25	0.07	0.74	0-2.4
	DCP	305	0.44	0.20	1.24	0-2.8
	ТСР	305	1.09	0.53	3.02	0-6.4
	тох	310	119.40	115.86	237.19	0-482

Source: ICR AUX1 database (USEPA 2000d).

Queries: Plants min 3x3, RAA - Other DBPs and Plants min 3x3, RAA and Max LRAA - TTHM & HAA5. See Appendix B for query language.

3.1.3.2 TTHM

Aggregate Data

TTHM measurements are the sum of concentrations of chloroform (CHCl₃), bromodichloromethane (BDCM), dibromochloromethane (DBCM), and bromoform (CHBr₃). Exhibit 3.9 presents summary statistics of plant-mean (except for the single highest observation) TTHM data collected under the ICR by source water and data type. (See Chapter 6 of the *Information Collection Rule Data Analysis* document [McGuire et al. 2002] and Appendix A for occurrence data on individual TTHM constituents.) Exhibit 3.10 shows the cumulative distribution of the plant-mean DS Average (or RAA) TTHM data for ICR surface and ground water plants. Exhibits 3.11 and 3.12 show the cumulative distributions of plant-mean TTHM single highest and plant-mean highest TTHM LRAA, respectively. Discussions of the findings follow the exhibits.

Exhibit 3.9 Summary of TTHM (µg/L) ICR Data for All Large Plants

_	1	Number of	Mean of	Median of	90th Percentile of	Range of Plant
Source	Data Type	Plants	Plant-Means	Plant-Means	Plant-Means	Means
	Finished Water	213	31.60	28.75	55.53	0-97
	DS Average (or RAA)	213	42.28	40.36	69.82	0-117
Surface	Single Highest	213	68.68	63.90	118.70	0-177
	Highest LRAA	213	49.29	45.80	80.67	0-124
	Max - Min ³	213	50.01	44.30	91.90	0-129
	Finished Water	82	9.69	1.48	24.75	0-119
Ground	DS Average (or RAA)	82	15.36	6.79	36.95	0-123
	Single Highest	82	32.32	18.50	74.40	0-300
	Highest LRAA	82	20.21	11.80	52.63	0-127
	Max - Min ³	82	26.53	15.40	60.00	0-300
	Finished Water	304	25.78	23.13	53.83	0-119
	DS Average (or RAA)	311	34.98	33.16	65.88	0-123
All ²	Single Highest	311	58.48	54.00	113.80	0-300
	Highest LRAA	311	41.38	39.50	78.20	0-127
	Max - Min ³	311	43.15	38.40	85.20	0-300

Notes: ¹ For a description of the data types, see "Aggregation of DBP Data" at the beginning of the subsection. ² The "All" plants include those with surface, ground, blended, mixed, or purchased source water types. Finished water data were not available for blended plants. ³Max-Min is the highest concentration of the four distribution system samples collected by a plant during the last four quarters of the ICR (16 possible values) minus the lowest concentration of the four distribution system samples reported during the last four quarters of the ICR.

Source: ICR AUX1 Database (USEPA 2000d).

Queries: Plants min 3x3, average by finish location - TTHM & HAA5, Plants min 3x3, RAA & Max LRAA - TTHM & HAA5 and Plants min 3x3, Single High - TTHM & HAA5, Plants min 3x3, Max-Min - TTHM & HAA5. See Appendix B for query language.





Query: Plants min 3x3, RAA & Max LRAA - TTHM & HAA5. See Appendix B for query language.

Source: ICR AUX1 Database (USEPA 2000d).





Source: ICR AUX1 Database (USEPA 2000d). Query: Plants min 3x3, Single High - TTHM & HAA5. See Appendix B for query language.



Exhibit 3.12 Cumulative Distribution of Highest LRAA for ICR TTHM Occurrence Data for Large Surface and Ground Water Plants

Source: ICR AUX1 Database (USEPA 2000d). Query: Plants min 3x3, RAA & Max LRAA - TTHM & HAA5. See Appendix B for query language.

TTHM has been regulated by EPA since the interim TTHM Rule, promulgated in 1979^2 . The TTHM Rule established an MCL of $100 \mu g/L$, calculated as an RAA of distribution system TTHM data measured at four locations, collected quarterly. As explained at the beginning of this section, an RAA is the average of the most recent four quarters of data; when data from a new quarter is obtained it replaces the data from the oldest quarter in the four quarter averaging. The Stage 1 DBPR sets an MCL for TTHM of 80 $\mu g/L$, calculated as an RAA. However, compliance with the Stage 1 DBPR was not required until 2002 for large surface water systems and 2004 for ground water and small surface water systems (USEPA 1998a). Thus, TTHM ICR data, collected in 1997 and 1998 and presented in this section, represents pre-Stage 1 DBPR conditions.

Plant-mean DS Average (or RAA) TTHM data can be used to estimate the percentage of plants that may have exceeded the Stage 1 MCLs at the time of the ICR. Although the 90th percentile RAA

² See Chapter 4 of the *Information Collection Rule Data Analysis* document (McGuire et al. 2002) for a thorough analysis of historical TTHM occurrence in large systems since the mid-to late- 1970's.

concentrations for ground and surface plants are less than the Stage 1 DBPR MCL of 80 μ g/L, the maximum plant-mean RAA concentrations are higher than 80 μ g/L for both plant types. From the cumulative distributions of TTHM RAA data (Exhibit 3.10), the following information can be derived:

- For surface water plants, approximately 4 percent (8 plants) had TTHM RAA levels above 80 µg/L; however, 13 percent (28 plants) had TTHM RAA levels above 64 µg/L (20 percent less than the Stage 1 DBPR MCL). The 64 µg/L level represents the safety margin occurrence level that utilities may try to achieve to avoid noncompliance.
- For ground water plants, approximately 2 percent (2 plants) had TTHM RAA levels above 80 μ g/L; however, 4 percent (3 plants) had TTHM RAA levels greater than 64 μ g/L.

It is important to note that ICR sampling locations may not be the locations that will be used for compliance with the Stage 1 DBPR nor were they the locations used for compliance with the 1979 TTHM rule. Also, because compliance is based on a RAA for the water system rather than the plant, it is possible for a plant to report TTHM data that is above the Stage 1 DBPR MCLs but for the system to still be in compliance with this regulation.

The Single Highest and Highest LRAA TTHM values in Exhibit 3.9 indicate that concentrations at some locations in the distribution system are much higher than DS Average concentrations. Many of these high values may not be reduced through compliance with the Stage 1 DBPR as high values are averaged over the whole system. The Stage 2 EA provides additional analyses of peak TTHM data as it relates to the Stage 1 DBPR and proposed Stage 2 DBPR.

Spatial and Temporal Variability

DBP sampling occurs throughout the distribution system, with particular attention on the finished water entry point (where the water enters the distribution system), average residence time points, and the maximum residence time point (where the water is typically the oldest). The location with the highest DBP levels can move throughout the distribution system due to distribution system hydraulics (e.g., changes in flow during peak hours, dead ends stagnating water). In Exhibit 3.13, the ICR data was evaluated to see with what frequency this is the case.

Exhibit 3.13 Location of Highest TTHM LRAA for ICR Occurrence Data for Large Surface and Ground Water Plants



Source:ICR AUX1 Database (USEPA 2000d).Query:Plants min 3x3, RAA & Max LRAA - TTHM & HAA5. See Appendix B for query language.

While the location of the highest TTHM LRAA occurs most often at the location with the maximum residence time, it is only that case in roughly 50 percent for surface water systems and roughly 40 percent for ground water systems. The difference between surface water and ground water plants is due to the more consistent water quality in ground water systems, and possibly the difference in treatment technologies employed at the different plants.

Exhibit 3.14 compares the location of the highest TTHM levels for chlorine and chloramine for surface water plants, and Exhibit 3.15 compares the location of the highest TTHM levels for chlorine and chloramine for ground water plants. For surface water plants, high TTHM values are more likely to occur at the MAX location for plants using free chlorine than plants using chloramination. Since chloramines are more stable throughout the distribution systems, their highest locations are more likely to change. The difference is lower for ground water plants, most likely due more stable influent water quality.



Exhibit 3.14 Location of Highest TTHM LRAA for ICR Occurrence Data by Plant Disinfectant Type for Large Surface Water Plants

Source: ICR AUX1 Database (USEPA 2000d).

Query: Plants min 3x3, RAA & Max LRAA - TTHM & HAA5. See Appendix B for query language.





Query: Plants min 3x3, RAA & Max LRAA - TTHM & HAA5. See Appendix B for query language.

Source: ICR AUX1 Database (USEPA 2000d).

3.1.3.3 HAA5

HAA5 measurements represent the sum of concentrations of monochloroacetic acid (MCAA), dichloroacetic acid (DCAA), trichloroacetic acid (TCAA), monobromoacetic acid (MBAA), and dibromoacetic acid (DBAA). Exhibit 3.16 presents summary statistics of plant-mean (except for the single highest observation) HAA5 data collected under the ICR by source water and data type. (See Chapter 6 of the *Information Collection Rule Data Analysis* document [McGuire et al. 2002] and Appendix A for occurrence data on individual HAA5 constituents.) Exhibit 3.17 shows the cumulative distribution of the plant-mean DS Average (or RAA) for HAA5 data for ICR surface and ground water plants. Exhibits 3.18 and 3.19 show the cumulative distributions of plant-mean HAA5 single highest and plant-mean highest HAA5 LRAA, respectively. Observations follow the exhibits.

		Number of	Mean of	Median of	90th Percentile of	Range of Plant
Source	Data Type ¹	Plants	Plant-Means	Plant-Means	Plant-Means	Means
Surface	Finished Water	213	24.60	20.85	45.78	0-104
	DS Average (or RAA)	213	29.07	24.38	52.31	0-116
	Single Highest	213	47.77	40.00	86.00	0-189
	Highest LRAA	213	33.66	28.30	58.37	0-124
	Max - Min ³	213	34.85	28.20	68.00	0-150
	Finished Water	82	6.35	0.33	18.83	0-97
Ground	DS Average (or RAA)	82	8.45	2.24	21.53	0-71
	Single Highest	82	17.79	6.30	46.30	0-124
	Highest LRAA	82	11.13	3.80	30.43	0-93
	Max - Min ³	82	14.68	6.20	43.60	0-94
	Finished Water	304	19.40	16.20	41.45	0-104
	DS Average (or RAA)	311	22.98	19.11	47.14	0-116
All ²	Single Highest	311	38.66	31.40	75.30	0-189
	Highest LRAA	311	26.93	22.53	55.73	0-124
	Max - Min ³	311	28.48	23.30	59.00	0-150

Exhibit 3.16 Summary of HAA5 ICR Data for All Large Plants (µg/L)

 Notes: ¹ For a description of the data types, see "Aggregation of DBP Data" at the beginning of the subsection. ² The "All" plants include those with surface, ground, blended, mixed, or purchased source water types. Finished water data were not available for blended plants. ³Max-Min is the highest concentration of the four distribution system samples collected by a plant during the last four quarters of the ICR (16 possible values) minus the lowest concentration of the four distribution system samples reported during the last four quarters of the ICR.
Source: ICR AUX1 Database (USEPA 2000d).
Queries: *Plants min 3x3, average by finish location - TTHM & HAA5, Plants min 3x3, RAA & Max LRAA - TTHM & HAA5* and *Plants min 3x3, Single High - TTHM & HAA5, Plants min 3x3, Max-Min - TTHM & HAA5.* See Appendix B for query language.





- Source: ICR AUX1 Database (USEPA 2000d).
- Query: Plants min 3x3, RAA & Max LRAA TTHM & HAA5. See Appendix B for query language.





Source: ICR AUX1 Database (USEPA 2000d). Query: Plants min 3x3, Single High - TTHM & HAA5. See Appendix B for query language.





Source: ICR AUX1 Database (USEPA 2000d). Query: Plants min 3x3, RAA & Max LRAA - TTHM & HAA5. See Appendix B for query language.

The Stage 1 DBPR sets an HAA5 MCL of 60 μ g/L, with the HAA5 regulated value calculated as the RAA of distribution system data measured at four locations per plant, collected quarterly. As noted previously, compliance with the Stage 1 DBPR was not required until 2002 for large surface water systems and 2004 for ground water and small surface water systems. Thus, HAA5 ICR data in this section represent pre-Stage 1 conditions. Further, unlike the case of TTHMs, HAAs were not regulated at all prior to the Stage 1 DBPR.

Plant-mean DS Average (or RAA) HAA5 data can be used to estimate the percent of plants that may have exceeded the Stage 1 MCLs at the time of the ICR. Although the 90th percentile RAA concentrations for ground and surface water plants are less than the Stage 1 DBPR MCL of 60 μ g/L, the maximum plant-mean RAA concentrations are higher than 60 μ g/L for both plant types. From the cumulative distributions of HAA5 RAA data (Exhibit 3.17), the following information can be derived:

- For surface water plants, approximately 6 percent (12 plants) had HAA5 RAA levels above 60 μg/L; however, 12 percent (26 plants) had HAA5 RAA levels greater than 48 μg/L (20 percent less than the Stage 1 DBPR MCL). The 48 μg/L level represents the safety margin occurrence level that utilities may try to achieve to avoid noncompliance.
- For ground water plants, approximately 2 percent (2 plants) had HAA5 RAA levels above 60 μ g/L; however, 4 percent (3 plants) had HAA5 RAA levels greater than 48 μ g/L.

It is important to note that ICR sampling locations may not be the locations used for compliance with the Stage 1 DBPR. Also, because compliance is based on a RAA for the water system rather than the plant, it is possible for a plant to report HAA5 data that is above the Stage 1 DBPR MCLs but still be in compliance with current regulations.

The Single Highest and Highest LRAA HAA5 values in Exhibit 3.16 indicate that concentrations at some locations in the distribution system are much higher than DS Average concentrations. Many of these high values may not be reduced by the Stage 1 DBPR. Chapter 4 provides additional analysis of peak HAA5 data as it relates to the Stage 1 DBPR and proposed Stage 2 DBPR.

Spatial and Temporal Variability

DBP sampling occurs throughout the distribution system, with particular attention on the finished water entry point (where the water enters the distribution system), average residence time points, and the maximum residence time point (where the water is typically the oldest). The location with the highest DBP levels can move throughout the distribution system due to distribution system hydraulics (i.e., changes in flow during peak hours, dead ends stagnating water). In Exhibit 3.20, the ICR data was evaluated to see with what frequency this is the case.



Exhibit 3.20 Location of Highest HAA5 LRAA for ICR Occurrence Data for Large Surface and Ground Water Plants

DSE

While the location of the highest HAA5 LRAA occurs most often at the location with the maximum residence time, it occurs at just over 40 percent for surface water systems and just over 25 percent for ground water systems. The difference between surface water and ground water plants is due to the more consistent water quality in ground water systems, and possibly the difference in treatment technologies employed at the different plants. Unlike TTHM, HAA5 are less likely to form within the distribution system and degrade more rapidly, so the highest HAA5 points are more likely to be found at locations that are not the maximum residence time.

AVG1 Distribution System Location AVG2

MAX

Exhibit 3.21 compares the location of the highest HAA5 levels for chlorine and chloramine for surface water plants, and Exhibit 3.22 compares the location of the highest HAA5 levels for chlorine and chloramine for ground water plants. For surface water plants, high HAA5 values are more likely to occur at the MAX location for plants using free chlorine than plants using chloramination. Since chloramines are more stable throughout the distribution systems, their highest locations are more likely to change. The difference is much larger for surface water plants than for ground water plants.

0%

FIN

Source: ICR AUX1 Database (USEPA 2000d). Query: Plants min 3x3, RAA & Max LRAA - TTHM & HAA5. See Appendix B for query language.





Source: ICR AUX1 Database (USEPA 2000d).

Query: Plants min 3x3, RAA & Max LRAA - TTHM & HAA5. See Appendix B for query language.





Source: ICR AUX1 Database (USEPA 2000d).

Query: Plants min 3x3, RAA & Max LRAA - TTHM & HAA5. See Appendix B for query language.

3.1.3.4 Bromate

Prior to Stage 1, bromate was not a regulated DBP. Therefore, little to no data exists for bromate occurrence. ICR requirements for bromate monitoring pertained to plants that use oxygenated disinfectants—ozone or chlorine dioxide. Bromate forms when these disinfectants react with bromide, which is commonly found in many source waters (see Exhibit 3.1 for source water bromide concentrations). Bromate can also occur as an impurity in hypochlorite solutions. Because bromide reacts immediately with ozone and bromate formation does not increase with residence time in the absence of a residual, monthly monitoring was required at the finished water sampling point but not in the distribution system. However, bromate formation does increase with contact time if there is a residual present.

Split samples for bromate were collected during the ICR: one set was analyzed by plant laboratory personnel or by EPA-certified contract laboratories, and one was analyzed by EPA. EPA's laboratory used a different laboratory analytical method and was able to detect bromate at much lower levels than most utility laboratories. The MRL for the utility method is $5.0 \mu g/L$, while the MRL for the EPA method is $0.20 \mu g/L$. Plant-mean bromate data are summarized in Exhibit 3.23. Ground water plant data were not included in this analysis—no ground water plants used chlorine dioxide, and only one used ozone.

For surface water plants using chlorine dioxide disinfection, approximately 47 percent of plantmean finished water bromate results were less than the MRL based on the EPA method, and 88 percent were less than the MRL based on the utility method. Bromate concentrations for plants using ozone are much higher than for plants using chlorine dioxide. Plant-mean finished water concentrations were as high as 7.2 μ g/L based on the EPA method and 6.4 μ g/L based on the plant laboratory method. It is difficult to compare values obtained by the EPA and plant laboratory methods. Because the MRL for the utility method is so high, most individual values were below the MRL of 5.0 μ g/L and thus were assigned a value of zero, affecting the calculation of the medians and means. For plants treating with chlorine dioxide, the median of the EPA method data was 0.02 μ g/L, while the median of the plant laboratory data was 0 μ g/L. For plants using ozone, the mean, median, and 90th percentile plant-mean bromate concentrations were higher based on the EPA method versus the plant laboratory method.

Data Type	Number of Plants	Mean of Plant-Means	Median of Plant-Means	90th Percentile of Plant-Means	Range of Plant-Means
Chlorine Dioxide Plants					
EPA Analytical Method	19	0.06	0.02	0.10	0-0.7
Plant Laboratory Analytical Method	16	0.09	0.0	0.64	0-0.8
Ozone Plants		-			
EPA Analytical Method	16	2.42	2.2	5.64	0-7.2
Plant Laboratory Analytical Method	14	1.75	0.0	5.09	0-6.4
Note: EPA laboratory anal	ytical method h	as an MRL of 0.0)2 µg/L and the p	lant laboratory analy	/tical method

Exhibit 3.23 Summary of Bromate in Finished Water, Plant-Mean ICR Data for All Large Plants (µg/L)

Note: EPA laboratory analytical method has an MRL of 0.02 μg/L and the plant laboratory analytical method has an MRL of 5.0 μg/L. These different MRLs greatly affect plant-mean bromate calculations.
Source: ICR AUX1 Database (USEPA 2000d).
Queries: Screened BROMATE EPA FIN and Screened BROMATE UTIL FIN. See Appendix B for query language.

3.1.3.5 Chlorite

ICR requirements for chlorite monitoring pertained only to plants that use chlorine dioxide for disinfection. Monthly monitoring was required at the finished water sampling location and at *three* rather than four locations in the distribution system. The three required monitoring locations were: (1) a location near the first customer; (2) a location with average residence time (AVG1), and; (3) the location with maximum residence time (DS Max).

Exhibit 3.24 summarizes plant-mean chlorite data. All data is for surface water systems (there were no ICR ground water systems that used chlorine dioxide). Different plant-mean data types are displayed to reflect the Stage 1 DBPR compliance calculations: (1) Plant-mean finished water chlorite concentrations reported by a plant; (2) Maximum of monthly finished water chlorite concentrations reported by a plant; (3) Plant-mean DS Average concentration (DS Average for chlorite is the average of data from the three distribution system sample locations described above) for a plant; (4) Maximum of monthly calculated DS Average concentration for a plant, and; (5) Single Highest concentration reported in one year in the distribution system for a plant.

The Stage 1 DBPR requires daily monitoring for chlorite at the finished water location and monthly monitoring at three locations in the distribution system. Under that rule, if a single daily sample at the finished water location exceeds 1,000 μ g/L, additional monitoring (outside the monthly monitoring requirement) at the three distribution system locations is then required. The MCL for chlorite is 1.0 mg/L (1,000 μ g/L), based on the average of the three distribution system locations. The maximum of monthly finished water chlorite concentrations ranged from 0 to 1,719 μ g/L. Approximately 78 percent of maximum finished water samples are below 1,000 μ g/L.

Data Type	Number of Plants	Mean of Plant-Means	Median of Plant-Means	90th Percentile of Plant-Means	Range of Plant-Means
Finished Water, Plant-Mean	18	432	461	768	2-1,105
Finished Water, Maximum Plant Month	18	720	690	1,300	20-1,719
DS Average, Plant-Mean	16	345	409	645	5-650
DS Average, Maximum Plant Month	16	572	653	871	20-1,100
Single Highest	16	645	700	886	41-1,200

Exhibit 3.24 Summary of Chlorite ICR Data (µg/L) for Large Surface Water Plants

Source: ICR AUX1 Database (USEPA 2000d).

Queries: Screened Chlorite DSAVG, Screened CHLORITE FIN, and Screened Chlorite Single High. See Appendix B for query language.

3.2 Medium and Small Systems

As discussed in Chapter 2, an estimated 12,224 surface water systems and 39,408 ground water systems (51,632 systems total) use disinfection and are subject to the Stage 1 and Stage 2 DBPRs. Although less than 1 percent of disinfecting systems fall into the large system size category (serving more than 100,000 people), they serve 55.1 percent of the total population served by disinfecting systems (see Exhibit 2.3). This is one reason that the ICR data collection effort focused on large plants. However, because roughly 45 percent of the population served by disinfecting systems obtains water from small and medium systems, it is also important to characterize DBP occurrence in drinking water provided by these systems.

There is no extensive, focused database similar to the ICR that provides information on DBP occurrence in small and medium systems. Consequently, it is necessary to use more limited and disparate sets of occurrence data, together with inferences drawn from the ICR data on large plants, to characterize DBP occurrence in medium and small systems.

This section presents available information on DBP occurrence, the occurrence of DBP precursors (e.g., TOC, bromide), and operational characteristics for small and medium systems in order to compare them to large system ICR data. One important factor to note when considering the possible similarities and differences in DBP levels among small, medium, and large systems is that the 1979 interim standards for TTHMs do not apply to systems serving fewer than 10,000 people. Some States do have DBP standards in place for small systems, but it is expected that nationally, a larger percentage of small systems will have higher DBP levels than large systems (serving 10,000 to 100,000 people) will be closer to those in large systems than the levels in small systems will, because these systems are currently regulated under the 1979 TTHM Rule.

3.2.1 Overview of Available Data for Medium and Small Systems

In addition to the ICR data on large plants, which can be used to draw inferences about small and medium systems, several data sets provide information specifically useful for evaluating small and medium systems. Chapter 1, section 1.5 describes each data set in full. A summary of each is provided below.

- <u>ICR Supplemental Survey (ICRSS)</u>. The ICRSS, conducted by EPA from March 1999 through February 2000, was designed to provide information to supplement the ICR data collection effort for microbiological and byproduct occurrence data. The ICRSS involved 40 randomly selected surface water systems in each of the small, medium, and large system size categories, as well as seven very large systems. The ICRSS did not collect DBP occurrence data, but did collect information on byproduct precursors in influent source waters, notably TOC and bromide levels.
- <u>The National Rural Water Association (NRWA) Survey</u>. Developed in cooperation with EPA, the NRWA Survey was designed to obtain relevant treatment, influent water quality, and byproduct occurrence information for a random sample of 117 small surface water systems (serving fewer than 10,000 people). The survey collected water quality and byproduct data during a cold weather period (November 1999 to March 2000) and a warm weather period (July 2000 to November 2000).

DBP samples were collected at a finished water location, a distribution system site with average residence time, and a distribution system site with maximum residence time. For small system DBP analyses presented in Section 3.2.2.2, samples at the average residence time location are given a weight three times that of data at the maximum residence location to produce a "DS Weighted Avg" result. The weighted average was used to make NRWA data comparable to ICR DS Average (or RAA) data, which is calculated by averaging data at four locations approximating the average and maximum residence time locations.

• <u>Water Utility Database (WATER:\STATS)</u>. Published by the American Water Works Association (AWWA), WATER\:STATS is derived from the AWWA Water Industry Database resulting from a 1996 survey of approximately 900 water utilities, mostly entities serving at least 10,000 people. The WATER:\STATS data used here are aimed mainly at characterizing relevant treatment and byproduct information for medium surface water plants.

Although 900 systems participated in the 1996 survey, the relevant table in WATER:\STATS contains data only from those systems that chose to respond to the section on water quality. WATER:\STATS does not contain data on individual samples; it contains averages, minima, and maxima for each parameter for each plant.

- <u>The Ground Water Supply Survey (GWSS)</u>. This survey, conducted by EPA in 1981–82, was designed to collect treatment, influent water quality, and finished water contaminant occurrence information on 979 small, medium, and large ground water systems from across the United States. Although TTHM data from this survey are available, they are probably not representative of current TTHM levels for large and medium systems because they were collected more than 20 years ago, prior to the implementation of the 1979 TTHM standard. Due to the rolling implementation schedule of the TTHM Rule, systems may or may not have been in compliance with the rule in 1981 and 1982. In addition, the TTHM data were collected only at the entry point to the distribution system, not from the distribution system itself.
- State Data. Data from several States were used to gain insights into the occurrence of DBPs and DBP precursors in surface water and ground water. For surface water, the data were available from eight States: Alaska, California, Illinois, Minnesota, Missouri, North Carolina, Texas, and Washington. The data from these States represent 562 small surface water systems. While the systems in these data sets were not randomly selected, they include at least 50 percent of the small systems in each State. Also, all the small surface water systems in these eight States together account for approximately one-third of all small non-purchased surface water systems in the United States, which is a significant sample. There were also some ground water data on DBPs available from seven States: Alaska, California, Florida, Illinois, North Carolina, Texas, and Washington.

The data available from each State are not exactly comparable; some States reported individual sample data, while others reported only plant averages. Some of the data appear to be from distribution system locations, while other samples are from the plant or from raw water. Samples in some States were collected quarterly, while in others, the time between samples at some plants was anywhere from two months to more than a year.

3.2.2 Surface Water Systems

DBP precursor occurrence data for medium and small surface water systems from the sources described in Section 3.2.1 are summarized in Exhibits 3.25 and 3.26. Exhibit 3.25 shows plant-mean data, while Exhibit 3.26 shows individual observations for the plants included in Exhibit 3.25. NRWA data were included only if both summer and winter data were available for a plant. ICRSS data were included only for plants that had data for at least three-fourths of the total possible number of samples. Detailed discussion of medium and small system data are provided in the next two subsections.

Exhibit 3.25 Summary of Non-ICR DBP Precursor Data for Medium and Small Surface and Ground Water Plants, Plant-Means

System Size		Number of	Mean of	Median of	90th Percentile	Range of			
& Type	Source of Data	Plants	Plant-Means	Plant-Means	of Plant-Means	Plant-Means			
Source Water T	Source Water TOC (mg/L as C)								
Small	NRWA	96	3.0	2.6	5.4	0.3-9.0			
Surface Water	ICRSS	38	2.4	2.1	4.5	0.1-7.1			
Medium	ICRSS	40	3.6	3.7	5.5	0.2-7.9			
Surface Water	WATER:\STATS	102	5.6	3.2	6.4	0.0-200			
Medium Ground Water	WATER:\STATS	51	2.3	0.8	7.0	0.0-25			
Source Water E	Bromide (mg/L)								
Small	NRWA	95	0.063	0.021	0.108	0-1.724			
Surface Water	ICRSS	38	0.020	0.000	0.044	0.000-0.274			
Medium Surface Water	ICRSS	40	0.050	0.016	0.092	0.000-0.534			
Source Water L	JV-254 (cm⁻¹)								
Small	NRWA	96	0.082	0.074	0.127	0.012-0.228			
Surface Water	ICRSS	38	0.074	0.051	0.113	0.016-0.444			
Medium Surface Water	ICRSS	40	0.093	0.083	0.171	0.029-0.208			

Notes: Small systems are those that serve fewer than 10,000 people; medium systems serve between 10,000 and 100,000 people. See text in Section 3.2.1 for a description of "Source of Data." Sources: USEPA 2001g; USEPA 2000k; AWWA 2000.

Exhibit 3.26 Summary of Non-ICR DBP Precursor Data for Medium and Small Surface and Ground Water Plants, Individual Observations

System Size		Number of			90th	
& Type	Source of Data	Observations	Mean	Median	Percentile	Range
Source Water T	OC (mg/L as C)					
Small	NRWA	192	3.0	2.6	5.5	0.3-9.9
Surface Water	ICRSS	384	2.4	1.8	5.7	0.0-17.0
Medium Surface Water	ICRSS	478	3.6	3.2	7.0	0.0-21.6
Source Water E	Bromide (mg/L)					
Small	NRWA	190	0.063	0.019	0.114	0-1.862
Surface Water	ICRSS	384	0.020	0.000	0.056	0-0.355
Medium Surface Water	ICRSS	473	0.050	0.014	0.116	0-0.865
Source Water L	JV-254 (cm ⁻¹)					
Small	NRWA	192	0.082	0.070	0.150	0-0.350
Surface Water	ICRSS	380	0.074	0.053	0.118	0.004-0.676
Medium Surface Water	ICRSS	467	0.1	0.1	0.2	0-0.805

Notes: Small systems are those that serve fewer than 10,000 people; medium systems serve between 10,000 and 100,000 people. See text in Section 3.2.1 for a description of "Source of Data." Sources: USEPA 2001g; USEPA 2000k.

3.2.2.1 Medium Surface Water Systems

The main purpose of this section is to evaluate medium surface water system DBP occurrence and water quality data and determine if these parameters in medium surface water systems are similar to those in large surface water systems. The data in the WATER:\STATS (AWWA 2000) and ICRSS (USEPA 2000k) data were primarily used for this purpose. All WATER:\STATS data in this section represent plant-average values.

WATER:\STATS occurrence data shows that source water types and quality in medium and large surface water systems are similar on a national level. Exhibit 3.27 indicates that medium and large surface water systems use very similar types of water sources. Exhibits 3.28 and 3.29 compare TOC data for different system sizes using WATER:\STATS and ICRSS data, respectively. These graphs show similar distributions of TOC occurrence in large and medium surface water systems. TOC occurrence can also be assessed by comparing medium system TOC data in Exhibit 3.25 to large system TOC data in Exhibit 3.1. WATER:\STATS and ICRSS values are similar to ICR TOC data, with median values of 3.2 mg/L, 3.7 mg/L, and 2.7 mg/L, respectively. ICRSS data on bromide and UV₂₅₄ levels, shown in Exhibit 3.25, are quite close to ICR plant levels (see Exhibit 3.1). Exhibits 3.30 and 3.31 show that medium and large systems have similar distributions of other parameters affecting treatability and, indirectly, DBP formation, such as turbidity and alkalinity.

The type of treatment technologies used by medium surface water systems is also similar to those used by large systems. As shown in Exhibits 3.32 through 3.34, medium and large systems are similar with respect to major categories of treatment (conventional vs. others), the use of key physical unit processes, and the use of specific disinfection methods among conventional plants. One reason that medium and large plants are similar is that both have historically been subject to the same regulatory requirements.

Exhibits 3.35 and 3.36 compare cumulative distributions of annual average TTHM levels in finished water and in distribution system water from WATER:\STATS for medium and large surface water systems, and confirm that the distributions are similar. Also, these cumulative distributions are consistent with TTHM values reported for large ICR plants earlier in this chapter for DS Averages (where the median plant-mean TTHM value is 41 μ g/L).





Source: WATER:\STATS (AWWA 2000).





Source: WATER:\STATS (AWWA 2000).





Source: ICRSS (USEPA 2000k).





Source: WATER:\STATS (AWWA 2000).





Source: WATER:\STATS (AWWA 2000).



Exhibit 3.32 Comparison of Treatment-In-Place for Medium and Large Surface Water Systems

Source: WATER:\STATS (AWWA 2000).





Source: WATER:\STATS (AWWA 2000).
Exhibit 3.34 Comparison of Disinfectant Type for Medium and Large Surface Water Systems Using Conventional Filtration



Source: WATER:\STATS (AWWA 2000).





Source: WATER:\STATS (AWWA 2000).



Exhibit 3.36 Comparison of Distribution System TTHM Data for Medium and Large Surface Water Systems

3.2.2.2 Small Surface Water Systems

The key sources of information for small surface water systems are the ICRSS, the NRWA Survey, and some State data. DBP Precursor data from these sources are summarized in Exhibits 3.25 and 3.26.

Exhibits 3.25 and 3.29 show that the distribution of TOC levels for small surface water plants differs somewhat from that for medium and large plants. Generally, small plants appear to have lower TOC levels (i.e., lower levels of byproduct precursors) than do the medium and large plants. However, at the upper end of the TOC distributions, above approximately the 90th percentile, small plant TOC levels are very similar to those of medium and large plants (see Exhibit 3.29).

Exhibits 3.37 through 3.40 provide the cumulative distributions of influent TOC, bromide, alkalinity, and temperature measurements from the NRWA Survey for winter and summer monitoring periods. Seasonal variability in TOC, bromide, and alkalinity appear low, although temperature was markedly different between winter and summer months (as expected). The TOC distribution in Exhibit 3.37 is similar to but slightly higher than that for small systems in the ICRSS (see Exhibit 3.25 for summary statistics on TOC). However, the ICRSS data set is more comprehensive than the NRWA data set. The ICRSS data reflect mean values for 12 months of sampling, whereas the NRWA data reflect a single sample for each site during two sampling periods. The bromide levels in Exhibit 3.38 are higher than the small surface waters in the ICRSS, but similar to medium ICRSS plants, as well as the ICR plants. The alkalinity levels in Exhibit 3.39 are higher than for ICRSS data (where the median for small systems is 50 mg/L as CaCO₃), but are similar to those observed for medium and large surface water plants in the ICR and WATER:\STATS. The temperature levels in Exhibit 3.40 are similar to those found in the ICR.

Source: WATER:\STATS (AWWA 2000).

Exhibits 3.41 to 3.44 illustrate some operational characteristics of small surface water plants that may correlate with the DBP levels observed in such plants. For example, Exhibit 3.41 shows that almost 50 percent of plants in the NRWA survey are in operation 12 hours a day or less. Some small plants are designed for a peak flow that may be seasonal, and the rest of the time they may operate at reduced flow. At these rates they may meet their production needs in less than 24 hours. Because they do not operate all of the time, small water systems may have water with higher residence times within their plant, depending on the size of their distribution system. This may increase DBP formation in cases where water stays for a long period of time in a clearwell or finished water storage facility after chlorination. In addition, many small systems have a smaller number of connections spread over areas as large, or larger, than medium and large water systems. Therefore, the water may be retained longer in pipes, thereby allowing for greater DBP formation.

Exhibit 3.42 indicates that only 15 percent of NRWA survey plants listed DBP control as a treatment objective. This is understandable due to the fact that small systems are not subject to the 1979 TTHM Rule. As shown in Exhibit 3.43, almost all NRWA plants use chlorine as a disinfectant, whereas 40 percent of ICR plants use chloramines, chlorine dioxide, and ozone, which are thought to contribute less to DBP formation than chlorine. With respect to disinfectant dose, small plants reported larger chlorine doses than the large ICR plants (Exhibit 3.44).



Exhibit 3.37 Plant Influent TOC Data for Small Surface Water Plants

Source: NRWA Survey (USEPA 2001g).



Exhibit 3.38 Plant Influent Bromide Data for Small Surface Water Plants



Exhibit 3.39 Plant Influent Alkalinity for Small Surface Water Systems



Exhibit 3.40 Plant Influent Temperature for Small Surface Water Systems













Sources: ICR AUX1 (USEPA 2000d); NRWA Survey (USEPA 2001g).

Exhibit 3.44 Comparison of Total Chlorine Doses in Large and Small Surface Water Plants Using Only Chlorination (Cl₂/Cl₂)



Sources: ICR AUX1 (USEPA 2000d); NRWA Survey (USEPA 2001g).

Although the NRWA survey, a key source of DBP data for small surface water systems, paralleled the ICR effort, the data collection was not as extensive. In the distribution system, NRWA samples were collected only at the location with the maximum residence time and one location with an average residence time. Exhibits 3.45 and 3.46 summarize the combined winter and summer NRWA results for TTHM and HAA5 occurrence data. Exhibits 3.47 through 3.49 provide the summer and winter cumulative distributions of the NRWA TTHM analyses for finished water, average residence time, and maximum residence time locations, respectively. Similar data are provided for HAA5 in Exhibits 3.50 through 3.52.

Despite the fact that small systems generally have lower DBP precursor concentrations than medium and large systems, NRWA results for small surface water systems show higher byproduct levels than in medium and large systems. This is understandable, given that small systems have not been subject to the requirements of the 1979 TTHM standards, which resulted in some medium and large systems making treatment changes (e.g., increased precursor removal or lower chlorination rates) to limit byproduct formation. Therefore, it is possible that small systems are applying greater amounts of chlorine while treating their water. Distribution system size may also play a part. Even though small systems serve a lower population, their distribution systems are typically as large, if not larger, than those of medium and large systems, increasing retention times in the pipes.

Exhibit 3.45 Summary of NRWA DBP Occurrence Data by Plant

Data Type	Number of Plants	Mean of Plant-Means	Median of Plant-Means	90th Percentile of Plant-Means	Range of Plant-Means			
ТТНМ								
Finished	96	62.78	46.20	137.00	0-326.05			
Avg Res Time	96	80.22	56.75	181.35	0-328.85			
DS Weighted Average	96	82.80	62.06	179.05	0-328.09			
Single High	96	118.40	97.20	224.80	0-451.40			
Max Res Time	96	90.54	67.15	188.30	0-325.80			
HAA5								
Finished	96	42.19	31.75	82.50	0-326.90			
Avg Res Time	96	46.17	35.30	85.00	0-327.50			
DS Weighted Average	96	45.32	33.99	83.89	0-261.56			
Single High	96	65.34	52.90	113.40	0-474.90			
Max Res Time	96	42.78	35.20	88.95	0-182.20			

Note: DS Weighted Average is calculated by giving the average residence time result a weight three times that of data at the maximum residence location. Refer to section 3.2.1 for a full description of NRWA data types.

Source: USEPA 2001g.

Exhibit 3.46 Summary of NRWA DBP Individual Observations

	Number of							
Data Type	Observations	Mean	Median	90th Percentile	Range			
ттнм								
Finished	192	62.78	45.10	132.90	0-471.50			
Avg Res Time	192	80.22	58.00	153.50	0-443.90			
Max Res Time	192	90.54	73.30	174.50	0-451.40			
HAA5								
Finished	192	42.19	28.80	87.30	0-481.10			
Avg Res Time	192	46.17	34.10	90.10	0-474.90			
Max Res Time	192	42.78	34.60	87.90	0-225.00			

Note: Refer to section 3.2.1 for a description of NRWA data types. Source: USEPA 2001g.



Exhibit 3.47 Distribution of TTHM Occurrence in Plant Finished Water





Exhibit 3.49 Distribution of TTHM Occurrence at the Point of Maximum Residence Time in the Distribution System



Source: NRWA Survey (USEPA 2001g).



Exhibit 3.50 Distribution of HAA5 Occurrence in Plant Finished Water

Exhibit 3.51 Distribution of HAA5 Occurrence at the Point of Average Residence Time in the Distribution System



Source: NRWA Survey (USEPA 2001g).





Exhibit 3.53 compares cumulative distributions of ICR, NRWA, and State plant-mean TTHM occurrence in distribution systems for small and large surface water plants. For the ICR, the running annual average of the last four quarters of distribution system data, based on plants with at least three sampling locations each quarter and at least three quarters of data, is plotted. The NRWA plant-means are weighted averages of the winter and summer average and maximum residence time samples, where average residence time samples are given weights three times those of maximum residence samples. (As noted previously, the NRWA data were weighted to make them comparable to ICR data, for which the DS Average is calculated for each quarter by averaging results of three samples from locations approximating average residence time and one sample at the maximum residence location.) The State data on small surface water systems were collected from over 500 small surface water systems. However, not all points on the graph represent the same type of data—the points are plant "averages," but some plants took only one sample, while others took multiple samples. The plants with single samples may explain some of the very high TTHM plant-means at the upper end of the distribution.

The median TTHM plant-mean value was 66 μ g/L and 62 μ g/L for State and NRWA data, respectively, while the median RAA value for the ICR was 41 μ g/L. The upper end of the NRWA distributions for TTHM is much higher than that of the ICR distributions. For example, NRWA 90th percentile TTHM concentrations are more than double their corresponding ICR concentrations. Only five ICR plants (2 percent) have TTHM levels exceeding 100 μ g/L (the MCL under the 1979 rule), while 23 (24 percent) NRWA plants and 192 (34 percent) plants in the State data set do.

The distribution of the State data shows TTHM levels at the upper end of the distribution are higher than those observed in the NRWA data. For example, the 90th percentile concentration in the State data set is $215 \ \mu g/L$, while the NRWA value is $168 \ \mu g/L$. This probably is due to the fact that some of the data points in the State data set were not averaged since some plants reported only one observation.

Exhibit 3.54 shows the co-occurrence of HAA5 and TTHM at NRWA plants. The TTHM and HAA5 values are plant-means weighted as discussed above. Roughly 22 percent of NRWA (small) plants had both TTHM and HAA5 plant-means exceeding Stage 1 DBPR limits, as compared to 1.4 percent of ICR surface water plants (see section 3.3.3 for ICR large plant DBP data analyses).

Although results in this section show that TTHM levels from the State data set are higher than the levels from the NRWA data set, the NRWA data may also be biased slightly high in terms of national DBP concentrations. This is because some States with high TOC (as compared to the national average and based on ICR data) are overrepresented in the survey, while other States with low TOC may be underrepresented. For example, plants in Louisiana, a high-TOC State, represent 4 percent of plants in the NRWA survey, but only 1 percent of small non-purchased surface water plants in the country, according to the Baseline Handbook (USEPA 2001e). The sampling results from plants in over- or underrepresented States may be skewing the distribution of TOC and DBP data.

Exhibit 3.53 Cumulative Distribution of Mean TTHM Occurrence in Distribution Systems for Small and Large Surface Water Plants



Sources: USEPA 2000I; USEPA 2000d; USEPA 2001g.



Exhibit 3.54 RAA TTHM vs. RAA HAA5 for 96 Small Surface Water Plants

Exhibit 3.55 shows the percent of plants that reported the maximum TTHM LRAA's at the finished water, average residence time, and maximum residence time locations. One would expect the locations with the highest residence time to have the highest DBP levels. However, for reasons stated in section 3.1.3.2, this is not always the case. Similar to ICR plants, NRWA plants have the highest TTHM LRAA concentration occurring at sites other than the maximum residence time monitoring site 33 percent of the time. The highest HAA5 LRAA occurred at the maximum residence time monitoring site in only 48 percent of the plants.

If TTHM and HAA5 occur at the same location rather than different locations, fewer monitoring sites would be needed to represent TTHM and HAA5 occurrence. However, this is not the case. The NRWA data set indicates that 56 percent of their plants experienced their highest LRAA TTHM and HAA5 concentrations at different locations in the distribution system. For plants that had their highest TTHM and HAA5 LRAA concentrations at the same location, it was not necessarily at the maximum residence time location. Exhibit 3.56 illustrates that for NRWA plants with the highest TTHM and HAA5 levels occurring at the same location, the highest TTHM and HAA5 LRAA simultaneously occurred at a location other than the maximum residence time monitoring location 36 percent of the time.

Exhibit 3.55 Percentage of DS Maximum Observations for TTHM and HAA5 by Sampling Location



Source: NRWA Survey (USEPA 2001g).

Exhibit 3.56 Frequency at Which Highest TTHM or HAA5 LRAAs Occurred at the Same Location for All NRWA Plants



Note: MAX = Maximum Residence Time Point, AVG = Average Residence Time Point, FINISH = Finished Water Point

3.2.3 Ground Water Systems

3.2.3.1 Medium Ground Water Systems

Only limited data are available on precursor and byproduct occurrence for medium disinfecting ground water systems. The most relevant information for assessing byproduct occurrence in ground water is that provided in the WATER:\STATS database. Exhibits 3.57 to 3.59 provide comparisons of influent average TOC levels, treatment used, and average TTHM levels for medium and large ground water systems in the WATER:\STATS data set.

The TOC data and the treatment process information show considerable similarity between medium and large systems. It should also be noted that the TOC distributions derived from WATER:\STATS for large and medium systems are similar to those observed for the large ground water plants in the ICR (see Exhibit 3.2). Average TTHM levels in medium and large ground water systems are also similar, as shown in Exhibit 3.59, based on WATER:\STATS data. The median average distribution system concentration for large ground water systems was 12 µg/L and for medium systems was 10 µg/L.

Exhibit 3.57 Annual Average TOC in Influent Water TOC for Ground Water Systems



Source: WATER:\STATS (AWWA 2000).

Exhibit 3.58 Treatment Summary for Ground Water Systems (Chlorinating and Non-Chlorinating)



Source: WATER:\STATS (AWWA 2000).





Source: WATER:\STATS (AWWA 2000).

3.2.3.2 Small Ground Water Systems

As with the small surface water systems, there is very limited information available on DBP precursor levels in small ground water systems that disinfect and insufficient data for determining national occurrence levels of DBPs (GWSS DBP data were not used because only distribution system entry point data were available).

Data are not available on influent TOC levels for small ground water systems that disinfect. However, there are some data available on effluent (finished water) TOC in small, medium, and large disinfecting ground water systems that can provide some insight into how small system DBP precursor levels compare with those at larger systems.

Exhibit 3.60 provides the effluent TOC data obtained in the 1982 GWSS. Though this information is somewhat dated, it is reasonable to assume the following with respect to these data: (1) the fraction of TOC removed in ground water systems is probably not substantial (based on comparisons of influent and effluent ICR TOC levels, as well as the absence of TOC-removal technologies, such as coagulation and filtration, from the majority of ground water plants), so these effluent TOC levels are reasonable indicators of influent TOC; (2) the levels of TOC in influent ground waters probably have not changed much since these data were collected (support for this is provided by comparing the effluent data for the large systems in the GWSS data set to the observed influent TOC levels for large systems in the ICR); and (3) the comparison across system sizes indicates that, on a national scale, TOC levels in small disinfecting ground water systems are similar to those of medium and large systems.

For TTHMs themselves, there are some data available for small ground water systems. These data were collected by seven States during 1998 and/or 1999, as described in the beginning of the chapter. Exhibit 3.61 shows annual average TTHM levels for more than 2,300 observations and compares them with ground water ICR running annual averages from the last four quarters of data collection. As with the surface water data, the State data are inconsistent. A few systems took only one sample per year; the average of such a value cannot easily be compared to that of a system taking 20 samples a year. This may explain some of the very high ground water values (e.g., the maximum value is $655 \mu g/L$). Overall, however, the State ground water data compare favorably with WATER:\STATS TTHM data for medium and large plants, with a median value of $3 \mu g/L$, much less than the median distribution system values for the other size categories (see Exhibit 3.25). The mean concentration, $17 \mu g/L$, is slightly below the mean of $19 \mu g/L$ for medium WATER:\STATS plants.

Exhibit 3.60 Comparison of Effluent TOC for Chlorinating Small, Medium, and Large Ground Water Systems



Source: GWSS (USEPA 1983).

Exhibit 3.61 Cumulative Distribution of TTHM Occurrence as Distribution System Average for Small and Large Ground Water Plants



Sources: USEPA 2000l; USEPA 2000d.

3.3 Analysis of Co-Occurrence

Due to the extensive data collection effort of the ICR, many analyses of source water quality parameters, treatment characteristics, and the resulting finished water quality are possible. This section presents the results of select analyses of the relationships between several source water quality parameters, disinfectants, and DBPs.

3.3.1 Total Organic Carbon Concentration and Alkalinity

Organic DBP formation occurs when disinfectants react with organic matter in water. The Stage 1 DBPR requires water systems to remove a certain percentage of TOC based on the TOC and alkalinity levels of the influent water. Exhibit 3.62 shows the percentage removals required by the Stage 1 DBPR in the 3×3 matrix for conventional plants. The last column of the matrix also applies to enhanced softening plants. There are various exceptions and alternative compliance criteria, which are explained in detail in the Stage 1 DBPR (USEPA 1998a).

Exhibit 3.62 Percent TOC Removal Requirements for Systems Employing Enhanced Coagulation

	Source Water Alkalinity (mg/L as CaCO ₃)			
Source Water TOC (mg/L)	0–60	>60–120	>120	
>2.0-4.0	35 %	25 %	15 %	
>4.0-8.0	45 %	35 %	25 %	
>8.0	50 %	40 %	30%	

Source: The Stage 1 Disinfectants/Disinfection Byproducts Rule (USEPA 1998a).

Exhibit 3.63 shows the percent of monthly samples in each TOC removal category over the last 12 months (January to December 1998) of the ICR monitoring period. Due to seasonal variation and other factors affecting source water, the percentage removal requirements for each plant may change from month to month as the influent TOC and alkalinity vary. Of the three alkalinity groups, the 60-120 mg/L category had the fewest samples. There were fewer samples with TOC concentrations greater than 4.0 mg/L (20 percent) than samples with TOC concentrations less than 4.0 mg/L (80 percent) over all three alkalinity ranges. In the 4.0-8.0 mg/L TOC range there is virtually no difference in the number of samples across the alkalinity groups. Many samples are close to the limits for a percentage removal group, indicating that the treatment requirements of a plant can easily change.

	Percentage				
Source Water TOC	Alkalinity (mg/L)				
Range (mg/L)	< 60	60 - 120	> 120	Total	
< 2.0	14%	10%	16%	39%	
2.0 - 4.0	14%	14%	13%	41%	
4.0 - 8.0	5%	5%	6%	16%	
> 8.0	1%	0%	2%	4%	
Total	34%	29%	37%	100%	

Exhibit 3.63 Distribution of Monthly Influent TOC (mg/L) and Monthly Influent Alkalinity (mg/L) Samples Based on ICR Data for All Large Plants

Source: ICR AUX1 database (USEPA 2000d).

Query: Screened INF TOC and ALK. See Appendix B for query language.

3.3.2 TOC, Bromide, and TTHM

TOC and bromide in raw water influence the formation of DBPs. Although the concentration of DBPs in the finished water is affected by the treatment applied, higher concentrations of TOC in the source water are expected to cause a greater occurrence of DBPs if not well controlled. Increases in the concentration of influent bromide are expected to shift the types of DBPs formed more to brominated species and raise the concentration by weight of DBPs, because bromide is heavier than chlorine. DBP formation and speciation, however, depend on many factors other than TOC and bromide, and include the type of disinfectant, pH, temperature, inorganic demand, and disinfectant residual. This section examines the relationship between influent TOC and bromide; this relationship is an indicator of the treatability of the water. A comparison of TOC and bromide source water occurrence is presented. Additional analyses were performed relating TOC and bromide occurrence in source water to TTHM and HAA5 levels in finished water.

Exhibit 3.64 contains the number of plants by each TOC and bromide category for Exhibits 3.65 through 3.68. There were 286 plants used for this analysis, which is fewer than the 311 presented previously for TTHM and HAA5 analyses of ICR data. The lower number is due to some plants not having enough bromide or TOC data, or both. There is one category, bromide "MRL-30" and TOC "3-4", which contains no plants meeting this criteria, and is reflected in the subsequent graphs as zero.

Exhibits 3.65 and 3.66 contain three-dimensional graphs comparing influent bromide, influent TOC, and finished water TTHM concentrations for surface and ground water plants. Exhibits 3.67 and 3.68 contain the same graphs for finished water HAA5 concentrations. The graphs were prepared by first categorizing each ICR plant by its mean influent water TOC and bromide concentration based on the last 12 months of the ICR collection period (TOC and bromide plant-means were based on monthly data for only those months that had corresponding TTHM or HAA5 data). This resulted in a 5 by 5 matrix according to the following bromide and TOC concentrations:

- TOC (mg/L): < 0 1; 1 2; 2 3; 3-4; and > 4
- Bromide (μ g/L): < 0; 0 30; 30 50; 50 100; > 100

For each of the 25 TOC/bromide categories, the mean and 90th percentile of all plant-mean TTHM and HAA5 concentrations were calculated using data from all of the plants in that category. Like influent

TOC and bromide, TTHM and HAA5 plant-mean data is based on the last 12 months of the ICR collection period. The highest level of TTHM, approximately 50 μ g/L, is indicated by a light-colored bar that identifies corresponding values of TOC of > 4 mg/L and of bromide of 30-50 μ g/L.

These comparisons have some uncertainty because TOC and bromide levels are from raw water, and TTHM and HAA5 are from finished water. It is therefore not known how treatment (other than disinfection) might have affected the TOC and bromide concentrations. If not controlled, higher influent TOC and bromide levels result in higher concentrations of DBPs. However, the pattern is not clear in this data set because the different treatment processes of most plants reduce DBP formation by removing TOC at varying levels. Also, bromide forms many other brominated acids that are not included in the measurements of TTHM or HAA5, making a direct correlation between TTHM, TOC, and bromide unlikely.

The general trend in all graphs is that TTHM formation increases as TOC increases, but there seems to be no simple correlation with bromide. These analyses do not account for the effect of alternative disinfectants, which may have been used in plants that had difficulty treating water with high TOC and particularly high bromide concentrations. In addition, because all TOC, bromide, and DBP concentrations are calculated as averages or 90th percentiles for each plant, the exhibits may not capture relationships between individual observations in one quarter.

The formation of HAA5 related to TOC and bromide in finished water is shown in Exhibit 3.67 and 3.68. The mean and 90th percentile graphs of all sampling points show that HAA5 formation increases as TOC increases and bromide decreases. Increasing bromide concentrations are expected to shift the speciation of HAAs to the more bromine-substituted species, which are not included in HAA5.

Exhibit 3.64 Count of Plants by Influent TOC and Bromide Concentrations Based on ICR Data for All Large Plants

	<mrl< th=""><th>MRL-30</th><th>30-50</th><th>50-100</th><th>>100</th><th>Total</th></mrl<>	MRL-30	30-50	50-100	>100	Total
<mrl-1< th=""><th>10</th><th>13</th><th>14</th><th>13</th><th>17</th><th>67</th></mrl-1<>	10	13	14	13	17	67
1-2	15	22	10	2	5	54
2-3	8	38	7	10	6	69
3-4	6	0	5	18	8	37
>4	2	15	7	16	19	59
Total	41	88	43	59	55	286

Source: ICR AUX1 Database (USEPA 2000d).

Query: Plants min 3x3, FW TTHM & HAA5 by Inf Bromide & TOC. See Appendix B for query language.

Exhibit 3.65 Finished Water TTHM Concentrations (Mean of Plant-Means) by Influent TOC and Bromide Concentrations Based on ICR Data for All Large Plants



Source: ICR AUX1 Database (USEPA 2000d).

Query: Plants min 3x3, FW TTHM & HAA5 by Inf Bromide & TOC. See Appendix B for query language.

Exhibit 3.66 Finished Water TTHM Concentrations (90th Percentile of Plant-Means) by Influent TOC and Bromide Concentrations Based on ICR Data for All Large Plants



Source: ICR AUX1 Database (USEPA 2000d).

Query: Plants min 3x3, FW TTHM & HAA5 by Inf Bromide & TOC. See Appendix B for query language.

Exhibit 3.67 Finished Water HAA5 Concentrations (Mean of Plant-Means) by Influent TOC and Bromide Concentrations Based on ICR Data for All Large Plants



Source: ICR AUX1 Database (USEPA 2000d). Query: Plants min 3x3, FW TTHM & HAA5 by Inf Bromide & TOC. See Appendix B for query language.

Exhibit 3.68 Finished Water HAA5 Concentrations (90th Percentile of Plant-Means) by Influent TOC and Bromide Concentrations Based on ICR Data for All Large Plants



Source: ICR AUX1 Database (USEPA 2000d). Query: Plants min 3x3, FW TTHM & HAA5 by Inf Bromide & TOC. See Appendix B for query language.

3.3.3 TTHM and HAA5

Co-occurrence of TTHM and HAA5 is important to investigate. Plants that are out of compliance with rules limiting TTHM and HAA5 levels will impact both TTHM and HAA5, as well as other unregulated DBPs. The extent to which plants have both TTHM and HAA5 levels greater than the MCL will dictate the number of systems that are out of compliance, and thus have to make treatment changes. Exhibits 3.69 through 3.74 compare DS Averages and Single Highest observations for TTHM and HAA5 samples drawn at the same location and time. Exhibits 3.69 and 3.70 show RAAs for surface water and ground water, respectively. Exhibits 3.71 and 3.72 compare each plant's highest TTHM and HAA5 LRAA values during the last four quarters of the ICR, and Exhibits 3.73 and 3.74 show individual Single Highest values. Each exhibit divides TTHM and HAA5 occurrence into quadrants, based on whether TTHM and/or HAA5 levels from a given sampling period exceed the Stage 1 DBPR MCLs of 80 μ g/L for TTHM and 60 μ g/L for HAA5. Each exhibit 3.69, 1.4 percent of plants have TTHM and HAA5 RAAs that exceed the contaminants' respective MCLs.

The graphs demonstrate a slight relation between TTHM and HAA5, with one increasing as the other increases. Most observations fall below the Stage 1 DBPR MCLs, especially for ground water data. Exhibits 3.71 and 3.72 also show that more plants would exceed both the 80 and 60 μ g/L TTHM and HAA5 levels if compliance were calculated as an LRAA under the Stage 1 DBPR, instead of the RAA method used to determine compliance.

Note that HAA5 does not represent all the HAAs, particularly the more bromine-substituted HAAs. Hence, for high bromide waters, HAA5 may not be as representative of brominated DBP formation as TTHM.





Source: ICR AUX1 Database (USEPA 2000d). Query: Plants min 3x3, RAA & Max LRAA - TTHM & HAA5. See Appendix B for query language.





Source:ICR AUX1 Database (USEPA 2000d).Query:Plants min 3x3, RAA & Max LRAA - TTHM & HAA5. See Appendix B for query language.



Exhibit 3.71 Highest LRAA TTHM versus Highest LRAA HAA5 for Large Surface Water Plants Based on ICR Data (N = 213)

Source:ICR AUX1 Database (USEPA 2000d).Query:Plants min 3x3, RAA & Max LRAA - TTHM & HAA5. See Appendix B for query language.



Exhibit 3.72 Highest LRAA TTHM versus Highest LRAA HAA5 for Large Ground Water Plants Based on ICR Data (N = 82)

Source:ICR AUX1 Database (USEPA 2000d).Query:Plants min 3x3, RAA & Max LRAA - TTHM & HAA5. See Appendix B for query language.





Query: Plants min 3x3, Single High - TTHM & HAA5. See Appendix B for query language.

Source: ICR AUX1 Database (USEPA 2000d).



Exhibit 3.74 Single Highest TTHM versus Single Highest HAA5 Based on ICR Data for Large Ground Water Plants (N = 82)

Source: ICR AUX1 Database (USEPA 2000d). Query: Plants min 3x3, Single High - TTHM & HAA5. See Appendix B for query language.

3.4 Analysis of Regional Trends

3.4.1 Occurrence of TOC

EPA evaluated ICR surface and ground water system data to determine if there were differences in influent water quality among regions. Exhibits 3.75a and 3.75b show average TOC concentrations by State for surface and ground water systems, respectively, using ICR data. Exhibit 3.75c shows average TOC concentrations by State for ground water systems using GWSS data. Surface water systems did not exhibit any notable regional trends; however, ICR and GWSS data show that Florida has very high TOC concentrations compared to other States. Florida also has the largest proportion of large ground water systems of all the States.

Exhibit 3.75a Influent Water TOC Occurrence Distribution for Large ICR Surface Water Systems



Source: ICR AUX1 Database (USEPA 2000d); mean of all plant-means for each State.



Exhibit 3.75b Influent Water TOC Occurrence Distribution for Large ICR Ground Water Systems

Source: ICR AUX1 Database (USEPA 2000d); mean of all plant-means for each State.





Source: GWSS (USEPA 1983); mean of all finished water TOC samples in the State.

3.4.2 Occurrence of Bromide

Regional trends in occurrence of bromide in source water were evaluated in the *Information Collection Rule Data Analysis* document (McGuire et al. 2002). Exhibits 3.76a and 3.76b shows the State by State average bromide levels in surface water and ground systems for each State. For surface water systems, Texas and Florida exhibit the highest influent bromide concentrations, both over 100 μ g/L. The Midwest region of the country exhibits high influent bromide concentrations overall whereas the Northeast water contains very little influent bromide. For ground water systems, there are far more States with very high (>100 μ g/l) bromide levels, primarily the southern half of the continental US.

Overall levels for ground water plants are typically higher than for surface water plants. This is due, in part because ground water has long contact time with geologic formations that can be sources of bromide. In addition, methyl bromide, used as a pesticide in agricultural operations, can contribute to high levels of bromide in water and may explain why the levels are much higher in the Midwest, South, and California – large agricultural centers.



Exhibit 3.76a Mean Influent Bromide Concentrations, Large ICR Surface Water Plants

Source: Chapter 14 Information Collection Rule Data Analysis document (McGuire et al. 2002).



Exhibit 3.76b Mean Influent Bromide Concentrations, Large ICR Ground Water Plants

Source: ICR AUX1 Database (USEPA 2000d); mean of all plant-means for each State.
4. National DBP Occurrence: Predicted Post-Stage 1 Baselines

Analyses of disinfection byproducts (DBP) occurrence data to support the development of the Stage 2 Disinfectants and Disinfection Byproducts Rule (DBPR) is complicated by the fact that existing national occurrence data were collected before systems had to comply with the Stage 1 DBPR¹. Although some plants might have begun making changes prior to the ICR in anticipation of the Stage 1 DBPR, EPA believes that DBP occurrence data in this document (specifically, total trihalomethanes [TTHMs] and haloacetic acids [HAA5]) can be used to represent pre-Stage 1 DBPR baseline conditions.

The purpose of this chapter is to support the development of the Stage 2 DBPR by predicting TTHM and HAA5 levels that could exist after the Stage 1 DBPR is implemented. Section 4.1 provides an overview of the methodology used to predict post-Stage 1 occurrence using the ICR data. Section 4.2 shows detailed derivation of post-Stage 1 occurrence for large ground and surface water plants. Section 4.3 focuses on the spatial and temporal variability in distribution system TTHM and HAA5 occurrence, including a separate analysis of chlorine (CL2) and chloramine (CLM) plants. EPA uses the methodology derived herein as one approach to characterize the post-Stage 1 occurrence for conducting the Stage 2 DBPR Economic Analysis (EA). EPA also uses an alternative method for estimating the post-Stage 1 occurrence (known as the Surface Water Analytical Tool [SWAT]) to support the Stage 2 DBPR EA (USEPA 2005a) for further elaboration on the description of these two methods. There was no suitable database available to conduct similar analyses for medium and small water systems. The Stage 2 DBPR EA (USEPA 2005a) presents a detailed discussion of the DBP occurrence for these systems following the Stage 1 DBPR.

4.1 Summary of Methodology for Predicting Post-Stage 1 DBP Occurrence for Large Plants

In order to develop a post-Stage 1 DBPR baseline, EPA's analysis must (1) identify which plants need to make treatment changes to meet the Stage 1 DBPR and (2) quantify the changes in TTHM and HAA5 occurrence resulting from those treatment changes. To this end, EPA developed a method called "The ICR Matrix Method" that manipulates occurrence data for non-compliant plants to generate a post-Stage 1 DBPR baseline². This method uses ICR data and is thus limited to large surface water and groundwater plants.

The method has three main steps. First, ICR plants are screened to ensure that there are enough TTHM and HAA5 distribution system data so as not to skew the analysis (See chapter 3 for a discussion of the screening process, including a discussion of data representativeness). Next plants are placed into compliant and non-compliant "bins" based on their calculated running annual average (RAA) and locational running annual average (LRAA) TTHM and HAA5 concentrations. Compliance is generally

¹Information Collection Rule (ICR) data were collected in 1997 and 1998. Other occurrence data for medium and small systems represent similar time frames. Surface water systems serving 10,000 or more people were required to comply with the Stage 1 DBPR by January 2002 and surface water systems serving fewer than 10,000 people and all ground water systems were required to comply with the Stage 1 DBPR by January 2004.

²Note that the Surface Water Analytical Tool (SWAT) was also used to predict changes in average DBP occurrence for Stage 1 and Stage 2. SWAT is discussed in detail in the Economic Analysis for the Stage 2 DBPR (USEPA 2005a).

based on the TTHM/HAA5 Maximum Contaminant Levels assuming a 20 percent safety margin (e.g., 64/48 RAA for the Stage 1 DBPR) to be consistent with recommendations made during the Microbial-Disinfection Byproducts Committee (M-DBP) Federal Advisory Committee Act (FACA) Meetings.

The third step in the ICR Matrix Method predicts the post-Stage 1 occurrence (after treatment changes are made to meet the Stage 1 DBPR) for those plants that are originally in the Stage 1 DBPR noncompliant bin. To do this, EPA relies on the assumption that some plants using chloramines and/or advanced technologies at the time of the ICR data collection (1997-1998) had installed those technologies in anticipation of the Stage 1 DBPR. Thus, the occurrence data for the subset of stage 1-compliant plants already using chloramines and/or an advanced technology can be used as indicators of occurrence data for those plants changing technology to meet the Stage 1 (and Stage 2) DBPR. EPA goes a step further and assumes that plants making treatment changes for the Stage 1 DBPR will also achieve compliance with the Stage 2 DBPR (TTHM/HAA5 LRAA of 80/60 ug/L with a 20 percent safety margin). The rationale for this assumption is summarized below (additional discussion can be found in the compliance forecast analysis of the Stage 2 EA):

- The Stage 2 DBPR is a required rule in the Safe Drinking Water Act (SDWA) Amendments of 1996. Details of the Stage 2 DBPR were published in the Agreement in Principle, which includes the Stage 2 MCLs, in December 2000, which is well before the Stage 1 compliance deadlines. It is less costly and, therefore, in a water system's best interest to develop a comprehensive treatment strategy to achieve simultaneous compliance with both Stage 1 and Stage 2.
- A large portion of systems use chloramines to achieve compliance with the Stage 1 DBPR. Chloramines generally result in lower spatial and temporal variability of TTHM and HAA5 concentrations in distribution systems compared to chlorine (this will be discussed further in Section 4.3). Therefore, systems that have switched to chloramines to comply with Stage 1 DBPR will likely have LRAA values already below 80 µg/L for TTHM and 60 µg/L for HAA5 and will not need to make a second treatment change to comply with the Stage 2 DBPR.

Analysis of screened plants revealed that 64 of the 172 Stage 2-compliant surface water plants (assuming a 20 percent safety margin) use chloramines and/or an advanced technology. For screened ground water plants, 12 of the 72 Stage 2-compliant plants (assuming a 20 percent safety margin) use chloramines and/or an advanced technology. EPA recognizes that there is uncertainty in using TTHM and HAA5 occurrence data for this subset of plants to represent the occurrence of TTHM and HAA5 once all plants have made changes to meet the Stage 1 DBPR. Plants may have installed advanced technologies for reasons other than the Stage 2 DBPR. Also, the occurrence of TTHM and HAA5 after a treatment change is dependent on plant-specific conditions. The Stage 2 EA provides some quantification of this uncertainty by using a second method to assess changes in average TTHM and HAA5 concentrations from the pre-Stage 1 to post-Stage 1 baselines.

4.2 Predicted Post-Stage 1 TTHM and HAA5 Occurrence

4.2.1 Large Surface Water Plants

This section provides the detailed derivation of the post-Stage 1 DBPR baseline for ICR surface water plants using the ICR Matrix Method. Exhibit 4.1 shows how the ICR Matrix Method can be used to estimate changes in average TTHM and HAA5 concentrations for large surface water systems, assuming a 20 percent safety margin for Stage 1 and Stage 2 MCLs. The left side of the exhibit contains two tables or

matrices that are divided into different "bins." The bins are cells defined by ranges of RAA values for TTHM and HAA5 across the top, and maximum LRAA values for TTHM and HAA5 down the left-hand side. The method works by moving plants from the non-compliant bin (Bin B2) into the compliant bin (Bin A1) in the second table, representing their actions to comply with Stage 1.

The number and percent of plants in each bin under pre-Stage 1 conditions is shown in the tables on the right-hand side of Exhibit 4.1. Plants are assigned to a bin based on their RAA and LRAA observations as calculated from the ICR data. Note that a plant is considered in one of the non-compliant bins if it exceeds either the TTHM or HAA5 MCL.

The analysis of TTHM and HAA5 levels for Stage 2-compliant plants that use advanced technologies and/or chloramines during the ICR is summarized in Exhibit 4.2. TTHM and HAA5 data for Stage 2-compliant plants in Exhibit 4.2 is assumed to represent TTHM and HAA5 occurrence for those plants that change technology to meet the Stage 1 rule (plants in Bin B2). This change in TTHM and HAA5 occurrence is reflected on the right hand side of Exhibit 4.1, Post-Stage 1 data (the row for "B2" is shaded for emphasis). The resulting change in the national average TTHM and HAA5 concentration is calculated as the weighted average for the Stage 1 / Stage 2 compliant plants and the non-compliant changers (see Exhibit 4.1, right-hand side, post-Stage 1 occurrence data, all plants).

Exhibit 4.1 ICR Matrix Method for Surface Water Plants for the Stage 1 DBPR (80/60 RAA), 20 Percent Safety Margin

	RAA		AA
		<64/48	>=64/48 (S1 non-compliant)
Max	<64/48	A1	
LRAA	>= 64/48 (S2 non- compliant)	A2	B2

Pre-Stage 1

	-			
		D	Average of P	ant Averages
	Number	Percent of	(uc	1/L)
Bin	of Plants	Plants	TTHM	HAA5
A1	136	64%	31.64	20.67
A2	36	17%	51.64	33.12
B2	41	19%	69.34	53.36
All Plants	213	100%	42.28	29.07

		R	AA
		<64/48	>=64/48 (S1 non-compliant)
Max	<64/48	A1+B2	
LRAA	>= 64/48 (S2 non- compliant)	A2	\times

Pc	Post-Stage 1									
		Number	Demostrat	Average of P	ant Averages					
		Number	Percent of	(ug)/L)					
	Bin	of Plants	Plants	TTHM	HAA5					
	A1	136	64%	31.64	20.67					
	A2	36	17%	51.64	33.12					
	B2	41	19%	31.48	19.14					
	All Plants	213	100%	34.99	22.48					

Notes: 1) In the first table on the left, A1 through B2 are the number of ICR plants that meet the criteria for each bin under pre-Stage 1 conditions. Their calculated average TTHM and HAA5 values based on the averages of all plant-averages are shown in the first table on the right. A total of 213 ICR plants were evaluated. 2) Each cell (bin) represents a range of the TTHM and HAA5 RAA concentrations and Maximum LRAA concentrations in µg/L (i.e., RAA <64/48 means the plant needs to have its TTHM RAA level below 64 µg/L and its HAA5 RAA level below 48 µg/L to be placed into the bin). The maximum TTHM or HAA5 result determines a plant's bin placement.

3) The crossed-out bin represents plants that have moved from out of compliance bins to in compliance bins.

4) The gray bin on the right-hand side represents plants that have moved into compliance with Stage 1. The TTHM and HAA5 concentrations for these plants is the average of the values for those ICR plants that are compliant with Stage 1 and Stage 2 and that use either an advanced technology, chloramines, or both (64 plants) from Exhibit 4.2.

Source: ICR Aux 1 database (USEPA, 2000h), analysis of ICR screened data (213 surface water plants). Queries: *Plants min 3x3, RAA & Max LRAA - TTHM & HAA5* and *Plants min 3x3.* See Appendix B for query language.

	Preferred Regulatory Alternative (20 Percent Safety Margin)				
Subset of Stage 2	Number of Mean TTHM Mean HAA5				
Compliant Plants	Plants (µg/L) (µg/L)				
CLM only	47	34.50	20.24		
ADV tech only	5	32.20	23.19		
CLM & Adv. tech	12	19.33	13.14		
Total	64	31.48	19.14		

Exhibit 4.2 TTHM and HAA5 Levels for Stage 2-Compliant Plants Using Chloramines and/or an Advanced Technology

Notes: All TTHM and HAA5 values represent the mean of plant-means CLM = chloramine Source: ICR Aux 1 database (USEPA, 2000h), analysis of ICR screened dat

Source: ICR Aux 1 database (USEPA, 2000h), analysis of ICR screened data (213 surface water plants). Queries: *Plants min 3x3, RAA & Max LRAA - TTHM & HAA5* and *Plants min 3x3.* See Appendix B for query language.

4.2.2 Large Ground Water Plants

EPA used the ICR Matrix Method to predict changes in average TTHM and HAA5 levels for large ground water systems following the Stage 1 and Stage 2 rules. A detailed description of the method can be found in the previous section.

Exhibit 4.3 shows the results of the ICR matrix method for the Stage 1 DBPR. The analysis of Stage 2-compliant, screened ground water plants using chloramines and/or an advanced technology at the time of the ICR data collection is shown in Exhibit 4.4. Average TTHM and HAA5 concentrations for those plants are used as indicators of TTHM and HAA5 concentrations after plants make treatment changes to meet rule requirements. The number of ICR GW plants that use chloramines and/or advanced disinfectants and comply with the Stage 2 DBPR is low: 12 plants (considering a 20 percent safety margin on compliance). This is roughly 15 percent of the total number of screened ground water plants. EPA compared TOC levels for the Stage 2-compliant ground water plants that use chloramines and/or an advanced technology to levels for the Stage 2 non-compliant plants and found them to be similar.

Exhibit 4.3 ICR Matrix Method for Ground Water Plants for the Stage 1 DBPR (80/60 RAA), 20 Percent Safety Margin

Pre-Stage 1

		R	AA
		<64/48	>=64/48 (S1 non-compliant)
Мах	<64/48	A1	
LRAA	>= 64/48 (S2 non- compliant)	A2	B2

	Number	Percent of	Average of P (ug	lant Averages g/L)
Bin	of Plants	Plants	TTHM	HAA5
A1	75	91%	11.62	5.50
A2	2	2%	35.29	31.71
B2	5	6%	63.54	43.37
All Plants	82	100%	15.36	8.45

		R	AA
		<64/48	>=64/48 (S1 non-compliant)
Max	<64/48	A1+B2	
LRAA	>= 64/48 (S2 non- compliant)	A2	\succ

Post-Stage 1

	Number	Percent of	Average of P (ug	lant Averages J/L)
Bin	of Plants	Plants	TTHM	HAA5
A1	75	91%	11.62	5.50
A2	2	2%	35.29	31.71
B2	5	6%	27.50	18.95
All Plants	82	100%	13.16	6.96

Notes:

1) In the first table on the left, A1 through B2 are the number of ICR plants that meet the criteria for each bin under pre-Stage 1 conditions. Their calculated average TTHM and HAA5 values based on the averages of all plant-averages are shown in the first table on the right. A total of 82 ICR plants were evaluated.

2) Each cell (bin) represents a range of the TTHM and HAA5 RAA concentrations and Maximum LRAA concentrations in µg/L (i.e., RAA <64/48 means the plant needs to have its TTHM RAA level below 64 μg/L and its HAA5 RAA level below 48 μg/L to be placed into the bin). The maximum TTHM or HAA5 result determines the bin placement.

3) The crossed-out bin represents plants that have moved from out of compliance bins to in compliance bins.

4) The gray bin on the right-hand side represents plants that have moved into compliance with Stage 1. The TTHM and HAA5 concentrations for these plants is the average of the values for those ICR plants that are compliant with Stage 1 and Stage 2 and that use either an advanced technology, chloramines, or both (12 plants) from Exhibit 4.4.

Source: ICR Aux 1 database (USEPA, 2000h), analysis of ICR screened data (82 ground water plants). Queries: Plants min 3x3, RAA & Max LRAA - TTHM & HAA5. See Appendix B for query language.

	Preferred Regulatory Alternative (20				
	Per	cent Safety Ma	argin)		
Subset of Stage 2	Number of	Mean TTHM	Mean HAA5		
Compliant Plants	Plants (µg/L) (µg/L)				
CLM only	10	29.0	19.4		
ADV tech only	0	0.0	0.0		
CLM & Adv. tech	2	19.9	16.5		
Total	12	27.5	18.9		

Exhibit 4.4 TTHM and HAA5 Levels for Stage 2-Compliant Ground Water Plants Using Chloramines and/or an Advanced Technology

Notes: All TTHM and HAA5 values represent the mean of plant-means.

Source: ICR Aux 1 database (USEPA, 2000h), analysis of ICR screened data (82 ground water plants). Queries: *Plants min 3x3, RAA & Max LRAA - TTHM & HAA5.* See Appendix B for query language.

4.2.3 Summary of Post-Stage 1 Occurrence

Exhibits 4.5 and 4.6 summarize post-Stage 1 DBPR TTHM and HAA5 data, respectively. The data are presented separately for different source water types (surface, ground, and all) and data types (plant-mean finished water, distribution system average, locational running annual average (LRAA), and single high). See section 3.1.3 for a description of the different data types. Plant-compliance was determined by using the Stage 1 DBPR MCLs with a 20 percent safety margin.

TTHM and HAA5 values decreased from pre-Stage 1 to post-Stage 1 for both surface water and ground water. For surface water plants, average values decreased by approximately 17 percent for TTHM (42.28 to 34.99 μ g/L) and 23 percent for HAA5 (29.07 to 22.47 μ g/L). For ground water plants, the decrease in DBP values was less substantial due to a lower percentage of plants changing their treatment technology. Still, average concentrations decreased approximately 14 percent for TTHM (15.36 to 13.16 μ g/L) and 18 percent for HAA5 (8.45 to 6.96 μ g/L)

For surface water systems results show that the highest LRAA for some Stage 1-compliant plants is significantly above the Stage 2 DBPR MCL of 80 μ g/L for TTHM and 60 μ g/L for HAA5. Single highest values are also still very high after Stage 1 compliance (maximum of 124 and 115 μ g/L for TTHM and HAA5, respectively, based on compliance with a safety margin). Single high values for ground water system are less, but LRAA values are still above the Stage 2 DBPR MCLs for some plants. However, LRAA values for HAA5 do not exceed the Stage 2 MCL without the safety margin. Section 4.3.1 provides more detailed analyses of the occurrence of individual TTHM and HAA5 peak measurements.

Exhibit 4.5 Summary of Post-Stage 1 TTHM Occurrence for ICR Plants, Stage 1 DBPR Safety Margin of 20%

		Number of	Mean of	Median of	90th Percentile of	Range of
Source	Data Type ¹	Plants	Plant-Means	Plant-Means	Plant-Means	Plant-Means
	Finished, Plant Mean	213	26.74	26.57	46.20	0-75
Surface	DS Average	213	34.99	34.23	55.61	0-64
Sunace	Single Highest	213	56.38	54.00	91.20	0-124
	Highest LRAA	213	40.95	39.68	65.73	0-98
	Finished, Plant Mean	82	8.64	1.48	24.75	0-58
Ground	DS Average	82	13.16	6.79	35.76	0-55
Ciouna	Single Highest	82	29.54	18.50	65.50	0-300
	Highest LRAA	82	18.46	11.80	52.63	0-99
	Finished, Plant Mean	302	21.91	20.63	45.90	0-87
All ²	DS Average	308	28.91	29.78	52.89	0-64
	Single Highest	308	48.82	50.30	87.30	0-300
	Highest LRAA	308	34.75	33.65	61.70	0-99

Notes: ¹ For a description of the data types. See "Aggregation of DBP Data" in section 3.1.3.
 ² The "All" plants include those with surface, ground, blended, mixed, or purchased source water types. Finished water data were not available for blended plants.
 Source: ICR AUX1 Database (USEPA 2000d). Derivation for DS Average shown in Exhibits 4.1 and 4.2 for surface water plants and in Exhibits 4.3

 Derivation for DS Average shown in Exhibits 4.1 and 4.2 for surface water plants and in Exhibits 4.3 and 4.4 for ground water plants. Derivation for other data types follows the same methodology.

 Queries:
 Plants min 3x3, average by finish location - TTHM & HAA5, Plants min 3x3, RAA & Max LRAA - TTHM & HAA5 and Plants min 3x3, Single High - TTHM & HAA5. See Appendix B for query language.

Exhibit 4.6 Summary of Post-Stage 1 HAA5 Occurrence for ICR Plants, Stage 1 MCL Safety Margin of 20%

		Number of	Mean of	Median of	90th Percentile of	Range of
Source	Data Type ¹	Plants	Plant-Means	Plant-Means	Plant-Means	Plant-Means
	Finished, Plant Mean	213	19.66	17.68	37.33	0-53
Surface	DS Average	213	22.48	21.34	39.22	0-48
Sunace	Single Highest	213	36.38	33.20	62.50	0-115
	Highest LRAA	213	26.13	24.90	45.65	0-60
	Finished, Plant Mean	82	5.03	0.33	17.53	0-34
Ground	DS Average	82	6.96	2.24	18.48	0-46
Giouna	Single Highest	82	14.79	6.30	45.00	0-84
	Highest LRAA	82	9.25	4.00	25.60	0-58
	Finished, Plant Mean	302	15.59	14.75	33.70	0-53
All ²	DS Average	308	18.09	17.32	35.18	0-48
	Single Highest	308	30.13	27.70	57.10	0-115
	Highest LRAA	308	21.32	20.57	41.45	0-60

Notes: ¹ For a description of the data types. See "Aggregation of DBP Data" in section 3.1.3.
 ² The "All" plants include those with surface, ground, blended, mixed, or purchased source water types. Finished water data were not available for blended plants.
 Source: ICR AUX1 Database (USEPA 2000d). Derivation for DS Average shown in Exhibits 4.1 and 4.2 for surface water plants and in Exhibits 4.3 and 4.4 for ground water plants. Derivation for other data types follows the same methodology.
 Queries: Plants min 3x3, average by finish location - TTHM & HAA5, Plants min 3x3, RAA & Max LRAA - TTHM & HAA5 and Plants min 3x3, Single High - TTHM & HAA5. See Appendix B for query language.

4.3 Variability of TTHM and HAA5 Occurrence, Post Stage 1 Conditions

This section supports the development of the Stage 2 DBPR by evaluating spatial and temporal variability of TTHM and HAA5 occurrence. Section 4.3.1 evaluates the spatial variability TTHM and HAA5 occurrence for large ground and surface water plants using ICR data. Section 4.3.2 evaluates the temporal variability in occurrence of individual TTHM and HAA5 peaks. Sections 4.3.3 and 4.3.4 characterize the occurrence of yearly average TTHM and HAA5 data at different locations.

4.3.1 Spatial Variability of TTHM and HAA5

For the purposes of this document, spatial variability in TTHM and HAA5 levels is defined as differences in TTHM and HAA5 concentrations at different locations in the distribution system. Spatial variability is influenced by system configuration (including storage facilities), residual disinfectant type (free chlorine versus chloramines), water age, and other factors that affect water quality, such as heterotrophic bacterial growth.

The extent of spatial variability in TTHM and HAA5 values can be an indicator of the impact of the Initial Distribution System Evaluation (IDSE). For most systems, compliance monitoring for the Stage 2 DBPR is proceeded by an IDSE. The goal of the IDSE is to identify sites that represent high TTHM and HAA5 concentrations in distribution systems. EPA expects there will some increase in high TTHM and HAA5 levels found in distribution systems from the ICR data collection to Stage 2 compliance monitoring due to the IDSE.

ICR screened data, consisting of 213 surface water plants and 82 ground water plants, were used to assess spatial variability of DBPs in distribution systems of large and medium surface water systems³. See section 3.1.3 for a description of the ICR data set and the screening method (only those plants with 3 of 4 quarters of data have TTHM and HAA5 data for at least 3 of 4 distribution system locations are considered in the analysis). EPA examined the spatial variability in the ICR data by examining the difference between the maximum LRAA value as reported for the last four quarters of the ICR (ICR LRAA_{max}) and the second highest LRAA as reported for the last four quarters of the ICR (ICR LRAA_{2ndHi}).

Exhibit 4.7a characterizes the difference between the ICR LRAA_{max} and ICR LRAA_{2ndHi} for surface water plants, and Exhibit 4.7b for ground water plants. Note that the average difference between the ICR LRAA_{max} and ICR LRAA_{2ndHi} is $5.99 \mu g/L$ for TTHM and $3.20 \mu g/L$ for HAA5. The cumulative distribution for ICR LRAA_{max} - LRAA_{2ndHi} for TTHM and HAA5 are shown in Exhibits 4.8a and 4.8b for surface water plants, and Exhibits 4.8c and 4.8d for ground water plants.

A large portion of systems are expected to use chloramines to achieve compliance with the Stage 1 DBPR. EPA believes that systems using chloramines as a secondary disinfectant can operate with a lower safety margin since chloramines generally result in lower spatial and temporal variability in distribution systems compared to chlorine. For example, Exhibit 4.7a below shows the average difference in DBP concentrations between the maximum and average residence time sites in ICR data separately for surface water plants using chlorine and chloramine. It shows that the average increase in concentration for chlorine plants is 8.13 μ g/L and the average increase for chloramine plants is 2.44 μ g/L. The increase in HAA5 concentrations is also higher for chlorine plants. At first gland, the opposite is true for ground water

³In the Stage 2 DBPR EA, EPA assess spatial variability for the subset of Stage 2 non-compliant plants to characterize the impacts of the IDSE. For this document, however, EPA examined all screened plants.

systems. However, the average $LRAA_{max}$ are much different, with CLM plants more than double the CL2 numbers, which is roughly the same ratio as the average differences.

Exhibit 4.7a Analysis of Variability for Stage 2 Non-Compliant Surface Water Plants

		TTHM		HAA5			
	CL2	CLM	All	CL2	CLM	All	
Number of Screened Plants	133	80	213	133	80	213	
Average of LRAA _{MAX}	53.17	42.84	49.29	36.17	29.49	33.66	
Average of LRAA _{2ndHI}	45.04	40.40	43.30	32.39	27.24	30.46	
Average of (LRAA _{MAX} - LRAA _{2ndHI})	8.13	2.44	5.99	3.78	2.25	3.20	
Max of (LRAA _{MAX} - LRAA _{2ndHI})	38.37	17.70	38.37	56.23	16.33	56.23	

Note: Represents all screened ICR SW plants with LRAAmax + (LRAAmax - LRAA2ndHi) > either 64 TTHM LRAA or 48 HAA5 LRAA that are in compliance with Stage 1.

Source: ICR AUX1 Database (USEPA 2000d).

Queries: Plants min 3x3, RAA & Max LRAA - TTHM & HAA5. See Appendix B for query language.

Exhibit 4.7b Analysis of Variability for Stage 2 Non-Compliant Ground Water Plants

		TT	HM		HAA5				
	CL2	CLM	None	All	CL2	CLM	None	All	
Number of Screened Plants	65	16	1	82	65	16	1	82	
Average of LRAA _{MAX}	14.83	35.45	126.50	20.21	5.27	31.37	68.33	11.13	
Average of LRAA _{2ndHI}	11.18	28.16	124.50	15.87	3.41	28.67	65.60	9.09	
Average of (LRAA _{MAX} - LRAA _{2ndHI})	3.65	7.30	2.00	4.34	1.86	2.70	2.73	2.04	
Max of (LRAA _{MAX} - LRAA _{2ndHI})	37.43	59.08	2.00	59.08	23.73	13.98	2.73	23.73	

Note: Represents all screened ICR GW plants with LRAAmax + (LRAAmax - LRAA2ndHi) > either 64 TTHM LRAA or 48 HAA5 LRAA that are in compliance with Stage 1.

Source: ICR AUX1 Database (USEPA 2000d).



Exhibit 4.8a Cumulative Distribution of ICR LRAA_{max} - ICR LRAA_{2ndHi} TTHM Screened Data, Surface Water Plants





Exhibit 4.8b Cumulative Distribution of ICR LRAA_{max} - ICR LRAA_{2ndHi} HAA5 Screened Data, Surface Water Plants

Source:

ICR AUX1 Database (USEPA 2000d). Plants min 3x3, RAA & Max LRAA - TTHM & HAA5. See Appendix B for query language. Queries:



Exhibit 4.8c Cumulative Distribution of ICR LRAA_{max} - ICR LRAA_{2ndHi} TTHM Screened Data, Ground Water Plants



ICR AUX1 Database (USEPA 2000d). Plants min 3x3, RAA & Max LRAA - TTHM & HAA5. See Appendix B for query language. Queries:



Exhibit 4.8d Cumulative Distribution of ICR LRAA_{max} - ICR LRAA_{2ndHi} HAA5 Screened Data, Ground Water Plants

Source: ICR AUX1 Database (USEPA 2000d).

4.3.2 Temporal Variability of TTHM and HAA5

Temporal, or seasonal, variability in TTHM and HAA5 levels is related to increased temperature and changes in source water quality. Temporal variability is typically much more of a factor for surface water systems compared to ground water systems. Even though TTHM and HAA5 RAA levels may be within the MCL, there are still observations that exceed the MCL and may pose health risks.

Exhibit 4.9a shows the delta of RAA and the individual quarterly averages for each plant. There is greater mean variation in surface water systems than in ground water system for both TTHM and HAA5. This is most likely a result of the greater temporal stability of water temperatures in ground water systems than in surface water systems, as described in section 3.1.1. Exhibits 4.9b and 4.9c display the quarterly TTHM deltas for surface and ground water plants, respectively. Exhibits 4.9d and 4.9e display the quarterly HAA5 deltas for surface and ground water plants, respectively. Similar to Exhibit 4.9a, Exhibits 4.9b and 4.9d show the greater temporal variability in surface waters when compared to Exhibits 4.9c and 4.9e.

		Number			90th				90th	
		of Plants	Mean	Median	Percentile	Range	Mean	Median	Percentile	Range
Surface Water	Quarter Three	198	-8.54	-7.39	5.21	-50.58 - 44.70	-2.90	-1.39	7.47	-44.83 - 41.85
	Quarter Four	208	2.26	1.56	16.02	-40.40 - 62.52	4.38	2.32	14.94	-40.97 - 82.07
	Quarter Five	195	8.96	5.61	29.64	-30.01 - 51.44	2.10	0.29	13.17	-24.58 - 57.28
	Quarter Six	202	-2.60	-1.54	10.89	-40.96 - 36.60	-3.70	-3.07	3.37	-62.56 - 26.06
Ground Water	Quarter Three	78	0.41	-0.09	5.09	-16.19 - 45.86	-0.50	0.00	2.05	-20.89 - 32.30
	Quarter Four	80	-1.42	-0.01	2.48	-28.78 - 18.73	-0.06	0.00	3.18	-26.65 - 6.53
	Quarter Five	75	0.88	0.00	7.34	-27.26 - 33.57	0.57	0.00	3.41	-7.40 - 29.63
	Quarter Six	75	0.22	0.00	7.26	-21.86 - 29.38	0.02	0.00	4.03	-6.38 - 9.75

Exhibit 4.9a Summary Statistics for Quarterly Average Minus RAA

Source: ICR AUX1 Database (USEPA 2000d).

Queries: Plants min 3x3, RAA & Quarterly Ave - TTHM & HAA5. See Appendix B for query language.

Exhibit 4.9b TTHM Quarterly Average Minus TTHM RAA for Surface Water Plants



Source: ICR AUX1 Database (USEPA 2000d).

Queries: Plants min 3x3, RAA & Quarterly Ave - TTHM & HAA5. See Appendix B for query language.

Exhibit 4.9c TTHM Quarterly Average Minus TTHM RAA for Ground Water Plants





Exhibit 4.9d HAA5 Quarterly Average Minus HAA5 RAA for Surface Water Plants



Source: ICR AUX1 Database (USEPA 2000d). Queries: Plants min 3x3, RAA & Quarterly Ave - TTHM & HAA5. See Appendix B for query language.

Exhibit 4.9e HAA5 Quarterly Average Minus HAA5 RAA for Ground Water Plants



Source: ICR AUX1 Database (USEPA 2000d). Queries: Plants min 3x3, RAA & Quarterly Ave - TTHM & HAA5. See Appendix B for query language.

4.3.3 Occurrence of Yearly Averages Above the MCL at Specific Locations

Cumulative distributions of LRAA values for each distribution system location (AVG1, AVG2, MAX, and DSE) for the subset of Stage 1-compliant plants are shown in Exhibit 4.10. Results indicate that there are still locations that regularly receive water over the MCLs, even after systems comply with the Stage 1 DBPR. From Exhibit 4.10, approximately 1.9 percent of plants (six out of 308) in compliance with Stage 1 MCLs of 64/48 RAA had one or more locations that, on average, exceeded 80 μ g/L as a TTHM LRAA for that same year. Customers served at these locations regularly received water with TTHM concentrations higher than the MCL.

Exhibit 4.11 shows similar results for HAA5. From Exhibit 4.11, shows that no plants in compliance with Stage 1 MCLS of 64/48 RAA exceeded 60 μ g/L as an LRAA. Evaluating TTHM and HAA5 results together, six plants have a maximum TTHM LRAA of 80 μ g/L or greater, or a maximum HAA5 LRAA of 60 μ g/L or greater.

Exhibit 4.10 Cumulative Percentage of TTHM LRAAs, All Plants in Compliance with 64/48 RAA (Stage 1 MCL with Safety Margin)



Source: ICR AUX1 Database (USEPA 2000d). Queries: *Plants min 3x3, RAA & Each LRAA - TTHM & HAA5.* See Appendix B for query language.

Exhibit 4.11 Cumulative Percentage of HAA5 LRAAs, All Plants in Compliance with 64/48 RAA (Stage 1 MCL with Safety Margin)



Source: ICR AUX1 Database (USEPA 2000d). Queries: *Plants min 3x3, RAA & Each LRAA - TTHM & HAA5.* See Appendix B for query language.

4.3.4 Occurrence of Peak DBPs at Locations Other Than the DS Maximum

The 1979 TTHM rule and Stage 1 DBPR monitoring locations must include a site reflecting maximum residence time in the distribution system with the intent of capturing the highest DBP levels in the distribution system. As described in Section 1.4.8, this location is referred to as the "DS Maximum" for the ICR data set. Analysis of the ICR data in this section show two important results: 1) the monitoring locations identified as the maximum residence time locations often did not represent those locations with the highest DBP levels and 2) the highest TTHM and HAA5 level often occurred at different points in the distribution system.

Exhibit 4.12 shows the frequency at which the maximum TTHM LRAA occurred at each distribution sampling location for screened surface water and ground water plants (see chapter 3 for a description of data screening). For surface water plants, more than half have the highest TTHM LRAA concentration occurring at sites other than the maximum residence time monitoring site. For ground water, more than 60 percent of ICR plants have the highest TTHM LRAA concentration occurring at sites other than the maximum residence time monitoring at sites other than the maximum residence time monitoring at sites other than the maximum residence time monitoring at sites other than the maximum residence time monitoring at sites other than the maximum residence time monitoring at sites other than the maximum residence time monitoring at sites other than the maximum residence time monitoring at sites other than the maximum residence time monitoring at sites other than the maximum residence time monitoring at sites other than the maximum residence time monitoring at sites other than the maximum residence time monitoring at sites other than the maximum residence time monitoring at sites other than the maximum residence time monitoring at sites other than the maximum residence time monitoring site.

For small surface water plants, the frequency at which the highest LRAA occurred at different locations can be analyzed using National Rural Water Association (NRWA) data. The analysis was only done for pre-Stage 1 conditions and was presented in Chapter 3 (Section 3.2).

Exhibit 4.13 compares the location of the highest TTHM levels for surface water plants using chlorine and surface water plants using chloramine. Exhibit 4.14 compares the location of the highest TTHM levels for ground water plants using chlorine and ground water plants using chloramine. For both surface water and ground water plants, high TTHM values are more likely to occur at the MAX location for chlorine plants than chloramine plants.

Exhibit 4.15 shows the frequency at which the maximum HAA5 LRAA occurred at each distribution sampling location for all plants that are in compliance with the Stage 1 DBPR. For surface water plants, more than 50 percent have the highest HAA5 LRAA concentration occurring at sites other than the MAX location, which is lower than the pre-Stage 1 value of 40.9 percent. For ground water, more than 70 percent ICR plants have the highest HAA5 LRAA concentration occurring at sites other than the MAX location. Exhibit 4.16 compares the location of the highest HAA5 levels for surface water plants using chloramine. Exhibit 4.17 compares similar data for ground water plants. For surface water, trends in HAA5 data are similar to TTHM - high HAA5 values are more likely to occur at the MAX location for chlorine plants than for chloramine plants. For ground water, however, the frequency that high HAA5 levels occurred at the MAX location was lower for chlorine than for chloramine plants.



















Exhibit 4.16 Location of Highest HAA5 LRAA for Screened ICR Surface Water Plants by Disinfectant Type

Source: Screened Plants from ICR AUX1 Database (USEPA 2000d).

Exhibit 4.17 Location of Highest HAA5 LRAA for Screened ICR Ground Water Plants by Disinfectant Type



Source: Screened Plants from ICR AUX1 Database (USEPA 2000d). Query: Plants min 3x3, RAA & Max LRAA - TTHM & HAA5. See Appendix B for query language.

EPA also analyzed whether the highest LRAA for TTHM and HAA5 occurred at the same location. If the highest TTHM and HAA5 values occur at the same location rather than different locations, fewer monitoring sites would be needed to represent TTHM and HAA5 occurrence. However, this is not the case. Only 47.7 percent of plants in compliance with Stage 1 DBPR experienced their highest LRAA TTHM and HAA5 concentrations at different locations in the distribution system. For plants that did have their highest LRAA TTHM and HAA5 concentrations at the same location, it was not necessarily the MAX location. Exhibit 4.13 illustrates that for Stage 1-compliant ICR plants with the highest TTHM and HAA5 levels occurring at the same location, the highest TTHM and HAA5 LRAA simultaneously occurred at the MAX location in 50.9 percent of the cases.

Exhibit 4.18 Frequency at Which Highest TTHM or HAA5 LRAAs Occurred at the Same Location, Plants in Compliance with 64/48 RAA (Stage 1 MCL with Safety Margin)



Source: ICR AUX1 Database (USEPA 2000d). Queries: *Plants min 3x3, RAA & Each LRAA - TTHM & HAA5.* See Appendix B for query language.

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Appendix A

TTHM and HAA5 Speciation Occurrence Data

Appendix A: TTHM and HAA5 Speciation Occurrence Data

A.1 Introduction

This appendix summarizes ICR data for the individual species of trihalomethanes (THM) and the five haloacetic acids (HAA5), providing descriptive statistics (number of samples, mean, median, 90th percentile, and range) for data collected during the Information Collection Rule (ICR) as contained in EPA ICR AUX1 database (USEPA 2000d). TTHM and HAA5 data were sampled quarterly, with the first quarter running from July to September 1997 and the last (sixth) quarter running from October to December 1998. The data present here presents the annual period from January 1998 to December 1998.

A.2 Trihalomethanes

The THMs sampled are chloroform (CHCl₃), bromodichloromethane (BDCM), dibromochloromethane (DBCM), and bromoform (CHBr₃). Total trihalomethane (TTHM) is the summation of those four THM. If any individual THM was not reported at a sampling location, no concentration was determined for TTHM at that location at that plant for that sampling period. All observations reported below the MRL for the individual species were considered zero for calculations, thus the minimum value for TTHM is zero when all four individual species are below the MRL.

Exhibit A.1 presents summary statistics for plant-means of THMs during the last 12 months of the ICR collection period for plants. Exhibit A.2 presents the mean concentrations, calculated by weight, and the percent each THM contributes to the TTHM concentration calculated from those means. For surface water plants, chloroform accounts for the majority of the TTHM concentrations at each location, ranging from 63.2 percent to 67.1 percent. For ground water plants, chloroform accounts for the majority of the TTHM concentrations at each location, ranging from 55.2 percent to 43.6 percent. The difference between surface and ground water systems is reflected in the increased percentages of dibromochloromethane and bromoform. This is most likely a switch to more brominated THMs as a result of the higher bromide levels in ground water as compared to surface water (see Chapter 3 for more information on bromide levels).

Number of		Mean of Plant	Median of	90th Percentile of	Range of				
Source	Plants	Means	Plant-Means	Plant-Means	Plant-Means				
Chloroform (CHCl₃)									
Surface	213	27.89	27.10	51.01	0.00-92.25				
Ground	82	6.86	1.52	16.94	0.00-104.03				
All	311	21.97 18.44 46.25		46.25	0.00-104.03				
	Bromodichloromethane (BDCM)								
Surface	213	9.39	8.35	17.97	0.00-34.13				
Ground 82		3.23 1.36 8.87		0.00-21.26					
All 311		7.77	6.70	16.79	0.00-34.13				
	Dibromochloromethane (DBCM)								
Surface	213	3.97	2.30	9.71	0.00-32.75				
Ground	82	3.14	1.27	8.25	0.00-33.25				
All	311	3.88	1.99	10.63	0.00-33.25				
Bromoform (CHBr ₃)									
Surface	213	1.03	0.00	2.41	0.00-25.25				
Ground	82	2.13	0.48	4.74	0.00-23.60				
All	311	1.35	0.08	3.53	0.00-25.25				

Exhibit A.1 Summary of Trihalomethane Data

Source:

ICR AUX1 Database (USEPA 2000d). *Plants min 3x3, RAA - TTHM Speciation.* See Appendix B for query language. Query:

Exhibit A.2	TTHM Speciation as a Concentration and Percent of Total

Data		Mean CHCl ₃		Mean BDCM		Mean DBCM		Mean CHBr ₃	
Source	Туре	µg/L	% of Total	µg/L	% of Total	µg/L	% of Total	µg/L	% of Total
		Α	B = A/(A+C+E+G)	С	D = C/(A+C+E+G)	Е	F = E/(A+C+E+G)	G	H = G/(A+C+E+G)
	FINISH	19.96	63.2%	7.52	23.8%	3.27	10.4%	0.85	2.7%
	DSE	26.12	65.2%	9.09	22.7%	3.87	9.7%	1.00	2.5%
Surface	AVG1	26.99	65.7%	9.23	22.5%	3.87	9.4%	0.99	2.4%
	AVG2	27.28	66.0%	9.19	22.2%	3.86	9.3%	0.99	2.4%
	MAX	31.26	67.1%	9.96	21.4%	4.23	9.1%	1.11	2.4%
	FINISH	5.35	55.2%	1.91	19.7%	1.45	14.9%	0.99	10.2%
Ground	DSE	6.32	47.2%	2.70	20.2%	2.56	19.1%	1.81	13.5%
	AVG1	7.12	43.6%	3.54	21.7%	3.42	20.9%	2.25	13.8%
	AVG2	6.79	44.1%	3.25	21.1%	3.17	20.6%	2.19	14.2%
	MAX	7.21	44.5%	3.41	21.0%	3.36	20.7%	2.23	13.8%

Source:

ICR AUX1 Database (USEPA 2000d). *Plants min 3x3, average by location - TTHM Speciation.* See Appendix B for query language. Query:

A.3 Haloacetic Acids (HAAs)

The haloacetic acids (HAAs) sampled were monochloroacetic acid (MCAA), dichloroacetic acid (DCAA), trichloroacetic acid (TCAA), monobromoacetic acid (MBAA), dibromoacetic acid (DBAA), bromochloroacetic acid (BCAA), bromodichloroacetic acid (BDCAA), chlorodibromoacetic acid (CDBAA), and tribromoacetic acid (TBAA). HAA5 is the sum of MCAA, DCAA, TCAA, MBAA, and, DBAA. The MRL for most HAA species is $1.0 \mu g/L$, except for MCAA ($2.0 \mu g/L$). All observations reported below the MRL for the individual species were considered zero for calculations.

Exhibit A.3 presents summary statistics for plant-means of HAAs. Exhibit A.4 presents the mean concentrations, calculated by weight, and the percent each HAA contributes to the HAA5 concentration calculated from those means. For surface water plants, DCAA accounts for the majority of the HAA5 concentrations at each location, ranging from 42.7 percent to 43.7 percent. For ground water plants, DCAA accounts for the majority of the HAA5 concentrations at each location, ranging from 42.7 percent to 43.7 percent. For ground water plants, DCAA accounts for the majority of the HAA5 concentrations at each location, ranging from 38.2 percent to 41.5 percent. The notable difference between surface and ground water systems is between TCAA and DBAA. For TCAA, There is a much higher range of TCAA percentages in surface water systems (39.0 percent to 41.6 percent) than ground water systems (19.0 percent to 21.0 percent). However, the opposite is true for DBAA, which has a much higher range of DBAA percentages in ground water systems (32.1 percent to 37.7 percent) than surface water systems (11.2 percent to 13.2 percent). This is most like a switch to more brominated HAAs as a result of the higher bromide levels in ground water as compared to surface water (see Chapter 3 for more information on bromide levels).

	Number of	Mean of Plant	Median of	90th Percentile of	Range of				
Source	Plants	Means	Plant-Means	Plant-Means	Plant-Means				
Monochloroacetic Acid (MCAA)									
Surface	213	1.12	0.50	3.15	0.00-9.99				
Ground	82	0.55	0.00	1.95	0.00-7.84				
All	311	0.93	0.30	2.89	0.00-9.99				
		Dichloro	acetic Acid (DC	AA)					
Surface	213	13.65	12.61	24.15	0.00-62.80				
Ground 82		4.57	0.44	12.84	0.00-42.63				
All	311	10.99	9.79	22.29	0.00-62.80				
	-	Trichloro	acetic Acid (TC	AA)					
Surface	213	13.06	11.19	25.90	0.00-60.08				
Ground	82	2.29	0.12	7.32	0.00-22.71				
All	311	9.86	7.32	22.71	0.00-60.08				
	Monobromoacetic Acid (MBAA)								
Surface	213	0.27	0.00	1.03	0.00-10.04				
Ground	82	0.13	0.00	0.56	0.00-1.39				
All	311	0.22	0.00	0.74	0.00-10.04				
Dibromoacetic Acid (DBAA)									
Surface	213	0.96	0.09	2.80	0.00-11.77				
Ground	82	0.91	0.09	3.03	0.00-12.85				
All	311	0.97	0.13	2.96	0.00-12.85				

Exhibit A.3 Summary of Haloacetic Acids

Source: ICR AUX1 Database (USEPA 2000d).

Query: Plants min 3x3, RAA - HAA5 Speciation. See Appendix B for query language.

	Data Mean MCAA		Mean DCAA		Mean TCAA		Mean MBAA		Mean DBAA		
Source	Туре	µg/L	% of Total	µg/L	% of Total	µg/L	% of Total	µg/L	% of Total	µg/L	% of Total
			B =		D =		F =		H =		J =
		Α	A/(A+C+E+G+	С	C/(A+C+E+G+	Е	E/(A+C+E+G+	G	G/(A+C+E+G+	I	I/(A+C+E+G+
			I)		I)		I)		I)		I)
	FINISH	0.98	3.6%	11.89	43.5%	10.66	39.0%	0.18	0.6%	3.62	13.2%
Surface	DSE	1.17	3.7%	13.61	43.7%	12.53	40.2%	0.24	0.8%	3.60	11.6%
	AVG1	1.16	3.6%	13.89	43.3%	13.16	41.0%	0.23	0.7%	3.65	11.4%
	AVG2	1.08	3.4%	13.51	42.7%	13.10	41.4%	0.31	1.0%	3.64	11.5%
	MAX	1.11	3.5%	13.78	42.7%	13.41	41.6%	0.34	1.0%	3.60	11.2%
Ground	FINISH	0.41	4.4%	3.58	38.2%	1.78	19.0%	0.06	0.6%	3.54	37.7%
	DSE	0.59	5.3%	4.48	40.2%	2.30	20.7%	0.14	1.3%	3.63	32.6%
	AVG1	0.56	5.1%	4.39	40.2%	2.20	20.1%	0.12	1.1%	3.65	33.4%
	AVG2	0.61	5.3%	4.75	41.5%	2.27	19.8%	0.15	1.3%	3.67	32.1%
	MAX	0.48	4.2%	4.61	41.1%	2.35	21.0%	0.11	1.0%	3.67	32.7%

Exhibit A.4 HAA5 Speciation as a Concentration and Percent of Total

Source: ICR AUX1 Database (USEPA 2000d).

Query: Plants min 3x3, average by location - HAA5 Speciation. See Appendix B for query language.

Appendix B

ICR Data Queries

Appendix B: ICR Data Queries

B.1 Introduction

This appendix provides the Structured Query Language (SQL) code used to extract data from the EPA Information Collection Rule (ICR) AUX1 database (USEPA 2000d). Data include water quality parameters, disinfectants, halogenated organic disinfection byproducts (DBPs), and inorganic DBPs. Section B.2 provides query language for data analyses, while B.3 provides all queries used for data screening. Queries are organized alphabetically. A brief description of each query precedes the SQL code.

B.2 Queries for Data Analysis

Last Ozone Contact Chamber

This query is used to extract the finished water total trihalomethanes (TTHM) and haloacetic acid (HAA5). Plants screened by whether they meet the 3x3 criteria defined in sections 1.4.8 and 3.1.3.

SELECT TUXOZCHM.ICRWTPID, [Plant Source Type, Last 12 Months].[Derived Source Type], Max(TUXOZCHM.CHMB_ID) AS MaxOfCHMB_ID, Count(TUXPLTMON.ICRWTPID) AS CountOfICRWTPID FROM (TUXPLTMON INNER JOIN TUXOZCHM ON (TUXPLTMON.SAMP_PER = TUXOZCHM.SAMP_PER) AND (TUXPLTMON.ICRWTPID = TUXOZCHM.ICRWTPID)) INNER JOIN [Plant Source Type, Last 12 Months] ON TUXOZCHM.ICRWTPID = [Plant Source Type, Last 12 Months].ICRWTPID WHERE (((TUXOZCHM.SAMP_PER)>=7) AND ((TUXPLTMON.WTP_DIS)="o3")) GROUP BY TUXOZCHM.ICRWTPID, [Plant Source Type, Last 12 Months].[Derived Source Type];

Plants min 3x3, average by finish location - TTHM & HAA5

This query is used to extract the finished water total trihalomethanes (TTHM) and haloacetic acid (HAA5). Plants screened by whether they meet the 3x3 criteria defined in sections 1.4.8 and 3.1.3.

SELECT [Plants min 3x3, by location & quarter - TTHM & HAA5].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5].EVNTNAME, [Plant Source Type, Last 12 Months].[Derived Source Type], Avg([Plants min 3x3, by location & quarter - TTHM & HAA5].TTHM1) AS AvgOfTTHM1, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5].HAA51) AS AvgOfHAA51, Count([Plants min 3x3, by location & quarter - TTHM & HAA5].ICRPWSID) AS CountOfICRPWSID, Sum(IIf([tthm1]>=40,1,0)) AS [Quarters > 40?], Sum(IIf([tthm1] >= 60, 1, 0)) AS [Quarters > 60?], Sum(IIf([tthm1] >= 75, 1, 0)) AS[Quarters > 75?], Sum(IIf([tthm1]>=80,1,0)) AS [Quarters > 80?], Sum(IIf([tthm1]>=100,1,0)) AS [Quarters > 100?], Sum(IIf([tthm1]>=120,1,0)) AS [Quarters > 120?], Sum(IIf([has51]>=30,1,0)) AS [Quarters > 120?], Sum(IIf([Quarters > 30?], Sum(IIf([haa51] >= 45,1,0)) AS [Quarters > 45?], Sum(IIf([haa51] >= 60,1,0)) AS[Quarters > 60-HAA5?], Sum(IIf([haa51]>=75,1,0)) AS [Quarters > 75-HAA5?], Sum(IIf([haa51]>=90,1,0)) AS [Quarters > 90?] FROM [Plants min 3x3, by location & quarter - TTHM & HAA5] INNER JOIN [Plant Source Type, Last 12 Months] ON [Plants min 3x3, by location & quarter - TTHM & HAA5].ICRWTPID = [Plant Source Type, Last 12 Months].ICRWTPID GROUP BY [Plants min 3x3, by location & quarter - TTHM & HAA5]. ICRPWSID, [Plants min 3x3, by location & quarter -TTHM & HAA5].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5].EVNTNAME, [Plant Source Type, Last 12 Months].[Derived Source Type] HAVING ((([Plants min 3x3, by location &

quarter - TTHM & HAA5].EVNTNAME)="Finish")) ORDER BY [Plants min 3x3, by location & quarter - TTHM & HAA5].ICRWTPID;

Plants min 3x3, FW TTHM & HAA5 by Inf Bromide & TOC

This query is used to extract the finished water TTHM and HAA5 with plants that have influent water data for bromide and total organic carbon (TOC). Plants are screened by whether they meet the 3x3 criteria defined in sections 1.4.8 and 3.1.3.

SELECT TUXSAMPLE.ICRWTPID, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5].HAA51) AS AvgOfHAA51, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5].TTHM1) AS AvgOfTTHM1, Avg(IIf([tuxsample].[evntname]="Influent",IIf([bromide]=-999, 0,[bromide]))) AS [Influent Bromide], Avg(IIf([tuxsample].[evntname]="Influent",IIf([toc]=-999, 0,[toc]))) AS [Influent TOC] FROM ([Plants min 3x3, by location & quarter - TTHM & HAA5] INNER JOIN TUXSAMPLE ON ([Plants min 3x3, by location & quarter - TTHM & HAA5].SAMP_QTR = TUXSAMPLE.SAMP_QTR) AND ([Plants min 3x3, by location & quarter - TTHM & HAA5].ICRWTPID = TUXSAMPLE.ICRWTPID)) LEFT JOIN TUXWQP ON TUXSAMPLE.EVENT_ID = TUXWQP.EVENT_ID WHERE ((([Plants min 3x3, by location & quarter - TTHM & HAA5].EVNTNAME)="finish")) GROUP BY TUXSAMPLE.ICRWTPID HAVING (((TUXSAMPLE.ICRWTPID)>100) AND ((Avg(IIf([tuxsample].[evntname]="Influent",IIf([bromide]= -999,0,[bromide])))) Is Not Null) AND ((Avg(IIf([tuxsample].[evntname]="Influent",IIf([toc]=-999,0,[toc])))) Is Not Null) ORDER BY TUXSAMPLE.ICRWTPID;

Plants min 3x3, RAA - Other DBPs

This query is used to extract the running annual average (RAA) for total organic halide (TOX), haloacetonitriles (HAN4), chloral hydrate (CH), chloropicrin (CP), 1,1-dichloropropanone (DCP), and 1,1,1-trichloropropanone (TCP). Plants are screened by whether they meet the 3x3 criteria defined in sections 1.4.8 and 3.1.3.

SELECT [Plants min 3x3, average by quarter - Other DBPs].ICRWTPID, [Plant Source Type, Last 12 Months].[Derived Source Type], Avg([Plants min 3x3, average by quarter - Other DBPs].AvgOfTOX1) AS [Plant Mean TOX], Avg([Plants min 3x3, average by quarter - Other DBPs].AvgOfHAN4_1) AS [Plant Mean HAN4], Avg([Plants min 3x3, average by quarter - Other DBPs].AvgOfCH1) AS [Plant Mean CH], Avg([Plants min 3x3, average by quarter - Other DBPs].AvgOfCP1) AS [Plant Mean CP], Avg([Plants min 3x3, average by quarter - Other DBPs].AvgOfDCP1) AS [Plant Mean CP], Avg([Plants min 3x3, average by quarter - Other DBPs].AvgOfTCP1) AS [Plant Mean DCP], Avg([Plants min 3x3, average by quarter - Other DBPs].AvgOfTCP1) AS [Plant Mean TCP] FROM [Plants min 3x3, average by quarter - Other DBPs] INNER JOIN [Plant Source Type, Last 12 Months] ON [Plants min 3x3, average by quarter - Other DBPs].ICRWTPID = [Plant Source Type, Last 12 Months].ICRWTPID GROUP BY [Plants min 3x3, average by quarter - Other DBPs].ICRWTPID, [Plant Source Type, Last 12 Months].[Derived Source Type];

Plants min 3x3, RAA & Each LRAA - TTHM & HAA5

This query is used to extract the RAA and locational running annual average (LRAA) for FIN, AVG1, AVG2, DSE, and MAX distribution system sampling locations for paired TTHM and HAA5 values. Plants are screened by whether they meet the 3x3 criteria defined in sections 1.4.8 and 3.1.3.

SELECT [Plants min 3x3, average by location - TTHM & HAA5].ICRPWSID, [Plants min 3x3, average by location - TTHM & HAA5].ICRWTPID, [Plant Source Type, Last 12 Months].[Derived Source Type], Avg([Plants min 3x3, average by quarter - TTHM & HAA5].AvgOfTTHM1) AS [TTHM RAA],

Avg([Plants min 3x3, average by quarter - TTHM & HAA5].AvgOfHAA51) AS [HAA5 RAA], Min(IIf([Plants min 3x3, average by location - TTHM & HAA5].[evntname]="FINISH",[Plants min 3x3, average by location - TTHM & HAA5].[AvgOfTTHM1])) AS [TTHM FIN RAA], Min(IIf([Plants min 3x3, average by location - TTHM & HAA5].[evntname]="DSE",[Plants min 3x3, average by location -TTHM & HAA5].[AvgOfTTHM1])) AS [TTHM DSE RAA], Min(IIf([Plants min 3x3, average by location - TTHM & HAA5].[evntname]="AVG",[Plants min 3x3, average by location - TTHM & HAA5].[AvgOfTTHM1])) AS [TTHM AVG RAA], Min(IIf([Plants min 3x3, average by location -TTHM & HAA5].[evntname]="AVG1",[Plants min 3x3, average by location - TTHM & HAA5].[AvgOfTTHM1])) AS [TTHM AVG1 RAA], Min(IIf([Plants min 3x3, average by location -TTHM & HAA5].[evntname]="AVG2",[Plants min 3x3, average by location - TTHM & HAA5].[AvgOfTTHM1])) AS [TTHM AVG2 RAA], Min(IIf([Plants min 3x3, average by location -TTHM & HAA5].[evntname]="MAX",[Plants min 3x3, average by location - TTHM & HAA5].[AvgOfTTHM1])) AS [TTHM MAX RAA], Min(IIf([Plants min 3x3, average by location -TTHM & HAA5].[evntname]="FINISH",[Plants min 3x3, average by location - TTHM & HAA5].[AvgOfHaa51])) AS [HAA5 FIN RAA], Min(IIf([Plants min 3x3, average by location - TTHM & HAA5].[evntname]="DSE",[Plants min 3x3, average by location - TTHM & HAA5].[AvgOfHaa51]]) AS [HAA5 DSE RAA], Min(IIf([Plants min 3x3, average by location - TTHM & HAA5].[evntname]="avg",[Plants min 3x3, average by location - TTHM & HAA5].[AvgOfHaa51]]) AS [HAA5 AVG RAA], Min(IIf([Plants min 3x3, average by location - TTHM & HAA5].[evntname]="avg1",[Plants min 3x3, average by location - TTHM & HAA5].[AvgOfHaa51])) AS [HAA5 AVG1 RAA], Min(IIf([Plants min 3x3, average by location - TTHM & HAA5].[evntname]="AVG2",[Plants min 3x3, average by location - TTHM & HAA5].[AvgOfHaa51])) AS [HAA5 AVG2 RAA], Min(IIf([Plants min 3x3, average by location - TTHM & HAA5].[evntname]="MAX".[Plants min 3x3, average by location - TTHM & HAA5].[AvgOfHaa51]]) AS [HAA5 MAX RAA] FROM ([Plants min 3x3, average by location - TTHM & HAA5] INNER JOIN [Plants min 3x3, average by quarter - TTHM & HAA5] ON ([Plants min 3x3, average by location -TTHM & HAA5].ICRWTPID = [Plants min 3x3, average by quarter - TTHM & HAA5].ICRWTPID) AND ([Plants min 3x3, average by location - TTHM & HAA5].ICRPWSID = [Plants min 3x3, average by quarter - TTHM & HAA5].ICRPWSID)) INNER JOIN [Plant Source Type, Last 12 Months] ON [Plants min 3x3, average by location - TTHM & HAA5].ICRWTPID = [Plant Source Type, Last 12] Months].ICRWTPID GROUP BY [Plants min 3x3, average by location - TTHM & HAA5].ICRPWSID, [Plants min 3x3, average by location - TTHM & HAA5].ICRWTPID, [Plant Source Type, Last 12 Months].[Derived Source Type];

Plants min 3x3, RAA & Max LRAA - TTHM & HAA5

This query is used to extract the RAA for TTHM and HAA5. Plants are screened by whether they meet the 3x3 criteria defined in sections 1.4.8 and 3.1.3.

SELECT [Plants min 3x3, average by location - TTHM & HAA5].ICRPWSID, [Plants min 3x3, average by location - TTHM & HAA5].ICRWTPID, [Plant Source Type, Last 12 Months].[Derived Source Type], Avg([Plants min 3x3, average by quarter - TTHM & HAA5].AvgOfTTHM1) AS [TTHM RAA], Avg([Plants min 3x3, average by quarter - TTHM & HAA5].AvgOfHAA51) AS [HAA5 RAA], Max([Plants min 3x3, average by location - TTHM & HAA5].AvgOfTTHM1) AS [TTHM LRAA], Max([Plants min 3x3, average by location - TTHM & HAA5].AvgOfHAA51) AS [HAA5 LRAA], IIf([tthm raa]<=80,IIf([haa5 raa]<=60,"Yes","No"),"No") AS [Stage 1 Compliant (w/out SF)], IIf([tthm raa]<=64,IIf([haa5 raa]<=60,"Yes","No"),"No") AS [Stage 2 Compliant (w/out SF)], IIf([tthm lraa]<=64,IIf([haa5 lraa]<=48,"Yes","No"),"No") AS [Stage 2 Compliant (w/ SF)] FROM ([Plants min 3x3, average by location - TTHM & HAA5] INNER JOIN [Plants min 3x3, average by quarter - TTHM & HAA5] INNER JOIN [Plants min 3x3, average by quarter - TTHM & HAA5].ICRWTPID = [Plants min 3x3, average by location - TTHM & HAA5].ICRWTPID = [Plants min 3x3, average by location - TTHM & HAA5].ICRWTPID = [Plants min 3x3, average by location - TTHM & HAA5].ICRWTPID = [Plants min 3x3, average by location - TTHM & HAA5].ICRWTPID = [Plants min 3x3, average by location - TTHM & HAA5].ICRWTPID = [Plants min 3x3, average by location - TTHM & HAA5].ICRWTPID = [Plants min 3x3, average by location - TTHM & HAA5].ICRWTPID = [Plants min 3x3, average by location - TTHM & HAA5].ICRWTPID = [Plants min 3x3, average by location - TTHM & HAA5].ICRWTPID = [Plants min 3x3, average by location - TTHM & HAA5].ICRWTPID = [Plants min 3x3, average by location - TTHM & HAA5].ICRWTPID = [Plants min 3x3, average by location - TTHM & HAA5].ICRWTPID = [Plants min 3x3, average by location - TTHM & HAA5].ICRWTPID = [Plants min 3x3, average by location - TTHM & HAA5].ICRWTPID = [Plants min 3x3, average by location - TTHM & HAA5].ICRWTPID = [Plants min 3x3, average by location - TTHM & HAA5].ICRWTPID = [Plants min 3x3, average by location - TTHM & HAA5].

average by quarter - TTHM & HAA5].ICRWTPID) AND ([Plants min 3x3, average by location - TTHM & HAA5].ICRPWSID = [Plants min 3x3, average by quarter - TTHM & HAA5].ICRPWSID)) INNER JOIN [Plant Source Type, Last 12 Months] ON [Plants min 3x3, average by location - TTHM & HAA5].ICRWTPID = [Plant Source Type, Last 12 Months].ICRWTPID WHERE ((([Plants min 3x3, average by location - TTHM & HAA5].EVNTNAME)<>"finish")) GROUP BY [Plants min 3x3, average by location - TTHM & HAA5].ICRWTPID, [Plants min 3x3, average by location - TTHM & HAA5].ICRPWSID, [Plants mi

Plants min 3x3, RAA & Quarterly Ave - TTHM & HAA5

This query is used to extract the difference between the plants RAA and each quarterly average for TTHM and HAA5. Plants are screened by whether they meet the 3x3 criteria defined in sections 1.4.8 and 3.1.3.

SELECT [Plants min 3x3, average by quarter - TTHM & HAA5].ICRWTPID, [Plant Source Type, Last 12 Months].[Derived Source Type], Avg([Plants min 3x3, average by quarter - TTHM & HAA5].AvgOfTTHM1) AS AvgOfAvgOfTTHM1, Avg([Plants min 3x3, average by quarter - TTHM & HAA5].AvgOfTHA1) AS AvgOfAvgOfTAA51, Sum(IIf([samp_qtr]=3,[avgOfthm1]))-Avg([AvgOfTTHM1]) AS [TTHM Q3 Delta], Sum(IIf([samp_qtr]=4,[avgOfthm1]))-Avg([AvgOfTTHM1]) AS [TTHM Q4 Delta], Sum(IIf([samp_qtr]=5,[avgOfthm1]))-Avg([AvgOfTTHM1]) AS [TTHM Q5 Delta], Sum(IIf([samp_qtr]=6,[avgOfthm1]))-Avg([AvgOfTTHM1]) AS [TTHM Q6 Delta], Sum(IIf([samp_qtr]=6,[avgOfthm1]))-Avg([AvgOfTTHM1]) AS [TTHM Q6 Delta], Sum(IIf([samp_qtr]=3,[avgOfhaa51]))-Avg([AvgOfTTHM1]) AS [TTHM Q6 Delta], Sum(IIf([samp_qtr]=4,[avgOfhaa51]))-Avg([AvgOfHaa51]) AS [HAA5 Q3 Delta], Sum(IIf([samp_qtr]=4,[avgOfhaa51]))-Avg([AvgOfHaa51]) AS [HAA5 Q3 Delta], Sum(IIf([samp_qtr]=4,[avgOfhaa51]))-Avg([AvgOfHaa51]) AS [HAA5 Q3 Delta], Sum(IIf([samp_qtr]=4,[avgOfhaa51]))-Avg([AvgOfHaa51]))-Avg([AvgOfHaa51]))-Avg([AvgOfHaa51])) AS [HAA5 Q5 Delta], Sum(IIf([samp_qtr]=6,[avgOfhaa51]))-Avg([AvgOfHaa51])) AS [HAA5 Q6 Delta] FROM [Plants min 3x3, average by quarter - TTHM & HAA5] INNER JOIN [Plant Source Type, Last 12 Months] ON [Plants min 3x3, average by quarter - TTHM & HAA5].ICRWTPID = [Plant Source Type, Last 12 Months].ICRWTPID GROUP BY [Plants min 3x3, average by quarter - TTHM & HAA5].ICRWTPID, [Plant Source Type, Last 12 Months].[Derived Source Type];

Plants min 3x3, Single High - TTHM & HAA5

This query is used to extract the single high value for TTHM and HAA5. Plants are screened by whether they meet the 3x3 criteria defined in sections 1.4.8 and 3.1.3.

SELECT [Plants min 3x3, max by quarter - TTHM & HAA5].ICRPWSID, [Plants min 3x3, max by quarter - TTHM & HAA5].ICRWTPID, Max([Plants min 3x3, max by quarter - TTHM & HAA5].MaxOfTTHM1) AS [Single High TTHM], Max([Plants min 3x3, max by quarter - TTHM & HAA5].MaxOfHAA51) AS [Single High HAA5] FROM [Plants min 3x3, max by quarter - TTHM & HAA5] GROUP BY [Plants min 3x3, max by quarter - TTHM & HAA5].ICRPWSID, [Plants min 3x3, max by quarter - TTHM & HAA5].ICRPWSID, [Plants min 3x3, max by quarter - TTHM & HAA5].ICRPWSID, [Plants min 3x3, max by quarter - TTHM & HAA5].ICRPWSID, [Plants min 3x3, max by quarter - TTHM & HAA5].ICRPWSID, [Plants min 3x3, max by quarter - TTHM & HAA5].ICRWTPID;

Plant Source Type, Last 12 Months

This query is used to determine the source water type for each plant in the ICR. It is used to determine source water type in the majority of queries mentioned in this appendix.

SELECT TUXPLTMON.ICRPWSID, TUXPLTMON.ICRWTPID, Count(TUXPLTMON.SAMP_PER) AS CountOfSAMP_PER, Iif(Count(IIf([msrc_cat]="SW",[msrc_cat]))>0,"SW", Iif(Count(IIf([msrc_cat]="Mix",[msrc_cat]))>0,"Mix",IIf(Count(IIf([msrc_cat]="GW",[msrc_cat]))>0,"G W",IIf(Count(IIf([msrc_cat]="PUR",[msrc_cat])),"PUR","NA")))) AS [Derived Source Type] FROM

TUXPLTMON WHERE (((TUXPLTMON.SAMP_PER)>=7)) GROUP BY TUXPLTMON.ICRPWSID, TUXPLTMON.ICRWTPID;

Screened BROMATE EPA FIN

This query extracts all bromate values, as measured by EPA, at the finished water point from plants with at least 9 of 12 months of data.

SELECT TUXSAMPLE.ICRWTPID, TUXPLTMON.WTP_DIS, [Plant Source Type, Last 12 Months].[Derived Source Type], TUXSAMPLE.EVNTNAME, Avg(IIf([bro3_epa]=-999,0,[bro3_epa])) AS [plant mean BROMATE], Count(TUXCLDIOX.BRO3_EPA) AS CountOfBRO3_EPA FROM (TUXPLTMON INNER JOIN (TUXSAMPLE INNER JOIN [Plant Source Type, Last 12 Months] ON TUXSAMPLE.ICRWTPID = [Plant Source Type, Last 12 Months].ICRWTPID) ON (TUXPLTMON.SAMP_PER = TUXSAMPLE.SAMP_PER) AND (TUXPLTMON.ICRWTPID = TUXSAMPLE.ICRWTPID) AND (TUXPLTMON.ICRPWSID = TUXSAMPLE.ICRPWSID)) INNER JOIN TUXCLDIOX ON TUXSAMPLE.EVENT_ID = TUXCLDIOX.EVENT_ID WHERE (((TUXSAMPLE.SAMP_PER)>=7)) GROUP BY TUXSAMPLE.ICRWTPID, TUXPLTMON.WTP_DIS, [Plant Source Type, Last 12 Months].[Derived Source Type], TUXSAMPLE.EVNTNAME HAVING (((TUXPLTMON.WTP_DIS)="CLX" Or (TUXPLTMON.WTP_DIS)="O3") AND ((TUXSAMPLE.EVNTNAME)="finish") AND ((Avg(IIf([bro3_epa]=-999,0,[bro3_epa]))) Is Not Null) AND ((Count(TUXCLDIOX.BRO3_EPA))>=9)) ORDER BY TUXSAMPLE.ICRWTPID;

Screened BROMATE UTIL FIN

This query extracts all bromate values, as measured by the utility, at the finished water point from plants with at least 9 of 12 months of data.

SELECT TUXSAMPLE.ICRWTPID, TUXPLTMON.WTP_DIS, [Plant Source Type, Last 12 Months].[Derived Source Type], TUXSAMPLE.EVNTNAME, Avg(IIf([bro3util]=-999,0,[bro3util])) AS [plant mean BROMATE], Count(TUXCLDIOX.BRO3UTIL) AS CountOfBRO3UTIL FROM (TUXPLTMON INNER JOIN (TUXSAMPLE INNER JOIN [Plant Source Type, Last 12 Months] ON TUXSAMPLE.ICRWTPID = [Plant Source Type, Last 12 Months].ICRWTPID) ON (TUXPLTMON.SAMP_PER = TUXSAMPLE.SAMP_PER) AND (TUXPLTMON.ICRWTPID = TUXSAMPLE.ICRWTPID) AND (TUXPLTMON.ICRPWSID = TUXSAMPLE.ICRPWSID)) INNER JOIN TUXCLDIOX ON TUXSAMPLE.EVENT_ID = TUXCLDIOX.EVENT_ID WHERE (((TUXSAMPLE.SAMP_PER)>=7)) GROUP BY TUXSAMPLE.ICRWTPID, TUXPLTMON.WTP_DIS, [Plant Source Type, Last 12 Months].[Derived Source Type], TUXSAMPLE.EVNTNAME HAVING (((TUXPLTMON.WTP_DIS)="CLX" Or (TUXPLTMON.WTP_DIS)="O3") AND ((TUXSAMPLE.EVNTNAME)="finish") AND ((Avg(IIf([bro3util]=-999,0,[bro3util]))) Is Not Null) AND ((Count(TUXCLDIOX.BRO3UTIL))>=9)) ORDER BY TUXSAMPLE.ICRWTPID;

Screened BROMIDE INF

This query extracts all bromide values at the influent water point from plants with at least 9 of 12 months of data.

SELECT TUXSAMPLE.ICRWTPID, Avg(IIf([bromide]=-999,0,[bromide])) AS [plant mean Bromide], [Plant Source Type, Last 12 Months].[Derived Source Type], Count(TUXWQP.BROMIDE) AS CountOfBROMIDE, TUXSAMPLE.EVNTNAME

FROM ([Plant Source Type, Last 12 Months] INNER JOIN TUXSAMPLE ON [Plant Source Type, Last 12 Months].ICRWTPID = TUXSAMPLE.ICRWTPID) INNER JOIN TUXWQP ON TUXSAMPLE.EVENT_ID = TUXWQP.EVENT_ID WHERE (((TUXSAMPLE.SAMP_PER)>=7)) GROUP BY TUXSAMPLE.ICRWTPID, [Plant Source Type, Last 12 Months].[Derived Source Type], TUXSAMPLE.EVNTNAME HAVING (((Avg(IIf([bromide]=-999,0,[bromide]))) Is Not Null) AND ((Count(TUXWQP.BROMIDE))>=9) AND ((TUXSAMPLE.EVNTNAME)="influent")) ORDER BY Avg(IIf([bromide]=-999,0,[bromide]));

Screened Chlorite

This query extracts all the chlorite levels in the distribution from plants with chlorine dioxide disinfection.

SELECT TUXSAMPLE.ICRWTPID, TUXPLTMON.WTP_DIS, [Plant Source Type, Last 12 Months].[Derived Source Type], Avg(IIf([chlorite]=-999,0,[chlorite])) AS [plant mean CHLORITE], Max(IIf([chlorite]=-999,0,[chlorite])) AS [Max of CHLORITE], TUXSAMPLE.SAMP PER, Count(TUXCHLORS.CHLORITE) AS CountOfCHLORITE FROM (TUXPLTMON INNER JOIN (TUXSAMPLE INNER JOIN [Plant Source Type, Last 12 Months] ON TUXSAMPLE.ICRWTPID = [Plant Source Type, Last 12 Months].ICRWTPID) ON (TUXPLTMON.SAMP_PER = TUXSAMPLE.SAMP_PER) AND (TUXPLTMON.ICRWTPID = TUXSAMPLE.ICRWTPID) AND (TUXPLTMON.ICRPWSID = TUXSAMPLE.ICRPWSID)) INNER JOIN TUXCHLORS ON TUXSAMPLE.EVENT_ID = TUXCHLORS.EVENT_ID WHERE (((TUXSAMPLE.EVNTNAME)="nfc" Or (TUXSAMPLE.EVNTNAME)="avg1" Or (TUXSAMPLE.EVNTNAME)="avg2" Or (TUXSAMPLE.EVNTNAME)="avg" Or (TUXSAMPLE.EVNTNAME)="max" Or (TUXSAMPLE.EVNTNAME)="dse")) GROUP BY TUXSAMPLE.ICRWTPID, TUXPLTMON.WTP_DIS, [Plant Source Type, Last 12 Months].[Derived Source Type], TUXSAMPLE.SAMP_PER HAVING (((TUXPLTMON.WTP_DIS)="CLX") AND ((Avg(IIf([chlorite]=-999,0,[chlorite]))) Is Not Null) AND ((Max(IIf([chlorite]=-999,0,[chlorite]))) Is Not Null) AND ((TUXSAMPLE.SAMP_PER)>=7)) ORDER BY TUXSAMPLE.ICRWTPID;

Screened Chlorite DSAVG

This query extracts all RAA of the chlorite levels in the distribution from plants with at least 9 of 12 months of data.

SELECT [Screened CHLORITE].ICRWTPID, [Screened CHLORITE].WTP_DIS, [Screened CHLORITE].[Derived Source Type], Avg([Screened CHLORITE].[plant mean CHLORITE]) AS [AvgOfplant mean CHLORITE], Count([Screened CHLORITE].SAMP_PER) AS CountOfSAMP_PER FROM [Screened CHLORITE] GROUP BY [Screened CHLORITE].ICRWTPID, [Screened CHLORITE].WTP_DIS, [Screened CHLORITE].[Derived Source Type] HAVING (((Count([Screened CHLORITE].SAMP_PER))>=9)) ORDER BY Avg([Screened CHLORITE].[plant mean CHLORITE]);

Screened CHLORITE FIN

This query extracts all chlorite values at the finished water point from plants with at least 9 of 12 months of data.

SELECT TUXSAMPLE.ICRWTPID, TUXPLTMON.WTP_DIS, [Plant Source Type, Last 12 Months].[Derived Source Type], Avg(IIf([chlorite]=-999,0,[chlorite])) AS [plant mean CHLORITE], Max(IIf([chlorite]=-999,0,[chlorite])) AS [Max of CHLORITE] FROM (TUXPLTMON INNER JOIN (TUXSAMPLE INNER JOIN [Plant Source Type, Last 12 Months] ON TUXSAMPLE.ICRWTPID = [Plant Source Type, Last 12 Months].ICRWTPID) ON (TUXPLTMON.SAMP_PER = TUXSAMPLE.SAMP_PER) AND (TUXPLTMON.ICRWTPID = TUXSAMPLE.ICRWTPID) AND (TUXPLTMON.ICRPWSID = TUXSAMPLE.ICRPWSID)) INNER JOIN TUXCHLORS ON TUXSAMPLE.EVENT_ID = TUXCHLORS.EVENT_ID WHERE (((TUXSAMPLE.EVNTNAME)="finish") AND ((TUXSAMPLE.SAMP_PER)>=7)) GROUP BY TUXSAMPLE.ICRWTPID, TUXPLTMON.WTP_DIS, [Plant Source Type, Last 12 Months].[Derived Source Type] HAVING (((TUXPLTMON.WTP_DIS)="CLX") AND ((Avg(IIf([chlorite]=-999,0,[chlorite]))) Is Not Null) AND ((Max(IIf([chlorite]=-999,0,[chlorite]))) Is Not Null) AND ((Count(TUXCHLORS.CHLORITE))>=9)) ORDER BY Avg(IIf([chlorite]=-999,0,[chlorite])));

Screened Chlorite Single High

This query extracts the highest chlorite value in the distribution from plants with at least 9 of 12 months of data. See section 1.4.8 for a detail description of single high calculations.

SELECT [Screened CHLORITE].ICRWTPID, [Screened CHLORITE].WTP_DIS, [Screened CHLORITE].[Derived Source Type], Max([Screened CHLORITE].[Max of CHLORITE]) AS [Single High Chlorite], Count([Screened CHLORITE].SAMP_PER) AS CountOfSAMP_PER FROM [Screened CHLORITE] GROUP BY [Screened CHLORITE].ICRWTPID, [Screened CHLORITE].WTP_DIS, [Screened CHLORITE].[Derived Source Type] HAVING (((Count([Screened CHLORITE]))>=9)) ORDER BY Max([Screened CHLORITE].[Max of CHLORITE]);

Screened EXCLXRES FIN

This query extracts all chlorine dioxide residual values at the finished water point from plants with at least 9 of 12 months of data.

SELECT TUXSAMPLE.ICRWTPID, TUXPLTMON.WTP_DIS, [Plant Source Type, Last 12 Months].[Derived Source Type], Avg(IIf([EXCLXRES]=-333,0,[EXCLXRES])) AS [Plant Mean CLX Residual], Count(TUXSAMPLE.ICRWTPID) AS CountOfICRWTPID FROM (TUXPLTMON INNER JOIN (TUXSAMPLE INNER JOIN [Plant Source Type, Last 12 Months] ON TUXSAMPLE.ICRWTPID = [Plant Source Type, Last 12 Months].ICRWTPID) ON (TUXPLTMON.SAMP_PER = TUXSAMPLE.SAMP_PER) AND (TUXPLTMON.ICRWTPID = TUXSAMPLE.ICRWTPID) AND (TUXPLTMON.ICRPWSID = TUXSAMPLE.ICRPWSID)) INNER JOIN TUXDISFRES ON TUXSAMPLE.EVENT_ID = TUXDISFRES.EVENT_ID WHERE (((TUXSAMPLE.EVNTNAME)="Finish") AND ((TUXSAMPLE.SAMP_PER)>=7)) GROUP BY TUXSAMPLE.ICRWTPID, TUXPLTMON.WTP_DIS, [Plant Source Type, Last 12 Months].[Derived Source Type] HAVING (((TUXPLTMON.WTP_DIS)="CLX") AND ((Avg(IIf([EXCLXRES]=-333,0,[EXCLXRES]))) IS NOT NUIL) AND ((Count(TUXSAMPLE.ICRWTPID))>=9));

Screened EXFCLRES FIN

This query extracts all free chlorine residual values at the finished water point from plants with at least 9 of 12 months of data.

SELECT TUXSAMPLE.ICRWTPID, TUXPLTMON.WTP_DIS, [Plant Source Type, Last 12 Months].[Derived Source Type], Avg(IIf([EXFCLRES]=-333,0,[EXFCLRES])) AS [Plant Mean Free CL2 Residual], Count(TUXSAMPLE.ICRWTPID) AS CountOfICRWTPID FROM (TUXPLTMON INNER JOIN (TUXSAMPLE INNER JOIN [Plant Source Type, Last 12 Months] ON TUXSAMPLE.ICRWTPID = [Plant Source Type, Last 12 Months].ICRWTPID) ON (TUXPLTMON.SAMP_PER = TUXSAMPLE.SAMP_PER) AND (TUXPLTMON.ICRWTPID = TUXSAMPLE.ICRWTPID) AND (TUXPLTMON.ICRPWSID = TUXSAMPLE.ICRPWSID)) INNER JOIN TUXDISFRES ON TUXSAMPLE.EVENT_ID = TUXDISFRES.EVENT_ID WHERE (((TUXSAMPLE.EVNTNAME)="Finish") AND ((TUXSAMPLE.SAMP_PER)>=7)) GROUP BY TUXSAMPLE.ICRWTPID, TUXPLTMON.WTP_DIS, [Plant Source Type, Last 12 Months].[Derived Source Type] HAVING (((TUXPLTMON.WTP_DIS)="CL2") AND ((Avg(IIf([EXFCLRES]=-333,0,[EXFCLRES]))) Is Not Null) AND ((Count(TUXSAMPLE.ICRWTPID))>=9));

Screened EXO3RES

This query extracts all ozone residual values at the finished water point from plants with at least 9 of 12 months of data.

SELECT [Last Ozone Contact Chamber].ICRWTPID, [Last Ozone Contact Chamber].[Derived Source Type], Avg(IIf([EXO3RES]=-333,0,[EXO3RES])) AS [Plant Mean Ozone Residual] FROM [Last Ozone Contact Chamber] INNER JOIN (TUXDISFRES INNER JOIN TUXOZCHM ON TUXDISFRES.EVENT_ID = TUXOZCHM.EVENT_ID) ON ([Last Ozone Contact Chamber].MaxOfCHMB_ID = TUXOZCHM.CHMB_ID) AND ([Last Ozone Contact Chamber].ICRWTPID = TUXOZCHM.ICRWTPID) WHERE (((TUXOZCHM.SAMP_PER)>=7)) GROUP BY [Last Ozone Contact Chamber].ICRWTPID, [Last Ozone Contact Chamber].[Derived Source Type] HAVING ((([Last Ozone Contact Chamber].[Derived Source Type])="sw") AND ((Count(TUXOZCHM.ICRWTPID))>=9));

Screened EXTCLRES FIN

This query extracts all total chlorine residual values at the finished water point from plants with at least 9 of 12 months of data.

```
SELECT TUXSAMPLE.ICRWTPID, TUXPLTMON.WTP_DIS, [Plant Source Type, Last 12
Months].[Derived Source Type], Avg(IIf([EXTCLRES]=-333,0,[EXTCLRES])) AS [Plant Mean Total
CL2 Residual], Count(TUXSAMPLE.ICRWTPID) AS CountOfICRWTPID FROM (TUXPLTMON
INNER JOIN (TUXSAMPLE INNER JOIN [Plant Source Type, Last 12 Months] ON
TUXSAMPLE.ICRWTPID = [Plant Source Type, Last 12 Months].ICRWTPID) ON
(TUXPLTMON.SAMP_PER = TUXSAMPLE.SAMP_PER) AND (TUXPLTMON.ICRWTPID =
TUXSAMPLE.ICRWTPID) AND (TUXPLTMON.ICRPWSID = TUXSAMPLE.ICRPWSID)) INNER
JOIN TUXDISFRES ON TUXSAMPLE.EVENT_ID = TUXDISFRES.EVENT_ID WHERE
(((TUXSAMPLE.EVNTNAME)="Finish") AND ((TUXSAMPLE.SAMP_PER)>=7)) GROUP BY
TUXSAMPLE.ICRWTPID, TUXPLTMON.WTP_DIS, [Plant Source Type, Last 12 Months].[Derived
Source Type] HAVING (((TUXPLTMON.WTP_DIS) Is Not Null And
(TUXPLTMON.WTP_DIS)<>"O3" And (TUXPLTMON.WTP_DIS)<>"CLX") AND
((Avg(IIf([EXTCLRES]=-333,0,[EXTCLRES]))) Is Not Null) AND
((Count(TUXSAMPLE.ICRWTPID))>=9));
```

Screened Plant Disinfectant Type

This query extracts all plant-month treatment plant disinfectant types for plants with at least 9 of 12 months of data.

TRANSFORM Count(TUXPLTMON.ICRWTPID) AS CountOfICRWTPID SELECT TUXPLTMON.ICRWTPID, [Plant Source Type, Last 12 Months].[Derived Source Type] FROM TUXPLTMON INNER JOIN [Plant Source Type, Last 12 Months] ON TUXPLTMON.ICRWTPID = [Plant Source Type, Last 12 Months].ICRWTPID WHERE (((TUXPLTMON.ICRWTPID)>99) AND ((TUXPLTMON.SAMP_PER)>=7)) GROUP BY TUXPLTMON.ICRWTPID, [Plant Source Type, Last 12 Months].[Derived Souce Type] PIVOT [WTP_DIS] & "/" & [DS_DIS];

Screened SW Plant-Mean CL2 Doses (w AUX2)

This query extracts all chlorine dose values from plants with at least 9 of 12 months of data. Chlorine dose values are taken from TUXCTSUM from the AUX2 database.

SELECT TUXCTSUM_AUX2.ICRWTPID, [Plant Source Type, Last 12 Months].[Derived Source Type], IIf([WTP DIS] & "-" & [DS DIS]="CL2-CL2","CL2 Only", IIf([WTP DIS] Like "*CLM*","CLM Only",[WTP_DIS] & "-" & [DS_DIS])) AS [System Disinfect Type], Avg(TUXCTSUM AUX2.TCL2DOSE) AS AvgOfTCL2DOSE, Count(TUXCTSUM AUX2.TCL2DOSE) AS CountOfTCL2DOSE FROM TUXPLTMON INNER JOIN ([Plant Source Type, Last 12 Months] INNER JOIN TUXCTSUM AUX2 ON ([Plant Source Type, Last 12 Months].ICRWTPID = TUXCTSUM AUX2.ICRWTPID) AND ([Plant Source Type, Last 12] Months].ICRPWSID = TUXCTSUM AUX2.ICRPWSID)) ON (TUXPLTMON.SAMP PER = TUXCTSUM AUX2.SAMP PER) AND (TUXPLTMON.ICRWTPID = TUXCTSUM AUX2.ICRWTPID) AND (TUXPLTMON.ICRPWSID = TUXCTSUM AUX2.ICRPWSID) WHERE (((TUXCTSUM AUX2.SAMP PER)>=7) AND ((TUXCTSUM AUX2.ICRWTPID)>99)) GROUP BY TUXCTSUM AUX2.ICRWTPID, [Plant Source Type, Last 12 Months].[Derived Source Type], IIf([WTP_DIS] & "-" & [DS_DIS]="CL2-CL2","CL2 Only", IIf([WTP_DIS] Like "*CLM*", "CLM Only", [WTP_DIS] & "-" & [DS_DIS])) HAVING (((IIf([WTP_DIS] & "-" & [DS_DIS]="CL2-CL2","CL2 Only",IIf([WTP_DIS] Like "*CLM*","CLM Only",[WTP_DIS] & "-" & [DS_DIS])))="CL2 Only" Or (IIf([WTP_DIS] & "-" & [DS_DIS]="CL2-CL2","CL2 Only",IIf([WTP_DIS] Like "*CLM*","CLM Only",[WTP_DIS] & "-" & [DS_DIS])))="CLM Only") AND ((Count(TUXCTSUM_AUX2.TCL2DOSE))>=9)) ORDER BY IIf([WTP_DIS] & "-" & [DS_DIS]="CL2-CL2","CL2 Only", IIf([WTP_DIS] Like "*CLM*", "CLM Only", [WTP_DIS] & "-" & [DS_DIS])), Avg(TUXCTSUM_AUX2.TCL2DOSE);

Screened SW Plant-Mean CLX Doses (w AUX2)

This query extracts all chlorine dioxide dose values from plants with at least 9 of 12 months of data. Chlorine dioxide dose values are taken from TUXCTSUM from the AUX2 database.

SELECT TUXPLTMON.ICRWTPID, [Plant Source Type, Last 12 Months].[Derived Source Type], TUXPLTMON.WTP_DIS, Avg(TUXCTSUM_AUX2.TCLXDOSE) AS AvgOfTCLXDOSE, Avg([tclxdose])-Min([tclxdose]) AS [Low Error], Max([tclxdose])-Avg([tclxdose]) AS [High Error], Count(TUXCTSUM_AUX2.TCLXDOSE) AS CountOfTCLXDOSE FROM (TUXPLTMON INNER JOIN TUXCTSUM_AUX2 ON (TUXPLTMON.SAMP_PER = TUXCTSUM_AUX2.SAMP_PER) AND (TUXPLTMON.ICRWTPID = TUXCTSUM_AUX2.ICRWTPID) AND (TUXPLTMON.ICRPWSID = TUXCTSUM_AUX2.ICRPWSID)) INNER JOIN [Plant Source Type, Last 12 Months] ON (TUXCTSUM_AUX2.ICRWTPID = [Plant Source Type, Last 12 Months].ICRWTPID) AND (TUXCTSUM_AUX2.ICRPWSID = [Plant Source Type, Last 12 Months].ICRWTPID) WHERE (((TUXPLTMON.SAMP_PER)>=7) AND ((TUXPLTMON.ICRWTPID)>99)) GROUP BY TUXPLTMON.ICRWTPID, [Plant Source Type, Last 12 Months].[Derived Source Type], TUXPLTMON.WTP_DIS HAVING ((([Plant Source Type, Last 12

Months].[Derived Source Type]) Is Not Null) AND ((TUXPLTMON.WTP_DIS)="CLX") AND ((Count(TUXCTSUM_AUX2.TCLXDOSE))>=9)) ORDER BY Avg(TUXCTSUM_AUX2.TCLXDOSE);

Screened SW Plant-Mean O3 Doses (w AUX2)

This query extracts all ozone dose values from plants with at least 9 of 12 months of data. Ozone dose values are taken from TUXCTSUM from the AUX2 database.

SELECT TUXPLTMON.ICRWTPID, [Plant Source Type, Last 12 Months].[Derived Source Type], TUXPLTMON.WTP_DIS, Avg(TUXCTSUM_AUX2.TO3DOSE) AS AvgOfTO3DOSE, Avg([to3dose])-Min([to3dose]) AS [Low Error], Max([to3dose])-Avg([to3dose]) AS [High Error], Count(TUXCTSUM_AUX2.TO3DOSE) AS CountOfTO3DOSE FROM (TUXPLTMON INNER JOIN TUXCTSUM_AUX2 ON (TUXPLTMON.SAMP_PER = TUXCTSUM_AUX2.SAMP_PER) AND (TUXPLTMON.ICRWTPID = TUXCTSUM_AUX2.ICRWTPID) AND (TUXPLTMON.ICRPWSID = TUXCTSUM_AUX2.ICRPWSID)) INNER JOIN [Plant Source Type, Last 12 Months] ON (TUXCTSUM_AUX2.ICRWTPID = [Plant Source Type, Last 12 Months].ICRWTPID) AND (TUXCTSUM_AUX2.ICRPWSID = [Plant Source Type, Last 12 Months].ICRPWSID) WHERE (((TUXPLTMON.SAMP_PER)>=7) AND ((TUXPLTMON.ICRWTPID)>99)) GROUP BY TUXPLTMON.ICRWTPID, [Plant Source Type, Last 12 Months].[Derived Source Type], TUXPLTMON.WTP_DIS HAVING ((([Plant Source Type, Last 12 Months].[Derived Source Type]) IS Not Null) AND ((TUXPLTMON.WTP_DIS)="O3") AND ((Count(TUXCTSUM_AUX2.TO3DOSE))>=9)) ORDER BY Avg(TUXCTSUM_AUX2.TO3DOSE);

Screened TEMP INF

This query extracts all total hardness values at the influent water point from plants with at least 9 of 12 months of data.

SELECT TUXSAMPLE.ICRWTPID, Avg(IIf([temp]=-999,0,[temp])) AS [plant mean Temp], [Plant Source Type, Last 12 Months].[Derived Source Type], Count(TUXWQP.TEMP) AS CountOfTEMP, TUXSAMPLE.EVNTNAME FROM ([Plant Source Type, Last 12 Months] INNER JOIN TUXSAMPLE ON [Plant Source Type, Last 12 Months].ICRWTPID = TUXSAMPLE.ICRWTPID) INNER JOIN TUXWQP ON TUXSAMPLE.EVENT_ID = TUXWQP.EVENT_ID WHERE (((TUXSAMPLE.SAMP_PER)>=7)) GROUP BY TUXSAMPLE.ICRWTPID, [Plant Source Type, Last 12 Months].[Derived Source Type], TUXSAMPLE.EVNTNAME HAVING (((Avg(IIf([temp]=-999,0,[temp]))) Is Not Null) AND ((Count(TUXWQP.TEMP))>=9) AND ((TUXSAMPLE.EVNTNAME)="influent")) ORDER BY TUXSAMPLE.ICRWTPID;

Screened INF TOC and ALK

This query extracts all paired TOC and alkalinity values at the influent water point from plants with at least 9 of 12 months of data.

SELECT [Screened ALK INF].[Derived Source Type], TUXSAMPLE.ICRWTPID, TUXSAMPLE.SAMP_PER, IIf([TOC]=-999,0,[TOC]) AS [INF TOC], IIf([ALK]=-999,0,[ALK]) AS [INF ALK], TUXSAMPLE.EVNTNAME FROM ([Screened ALK INF] INNER JOIN TUXSAMPLE ON [Screened ALK INF].ICRWTPID = TUXSAMPLE.ICRWTPID) INNER JOIN TUXWQP ON TUXSAMPLE.EVENT_ID = TUXWQP.EVENT_ID WHERE (((TUXSAMPLE.SAMP_PER)>=7) AND ((IIf([TOC]=-999,0,[TOC])) IS Not Null) AND ((IIf([ALK]=-999,0,[ALK])) IS Not Null) AND ((TUXSAMPLE.EVNTNAME)="Influent"));

Screened TOC INF

This query extracts all TOC values at the influent water point from plants with at least 9 of 12 months of data.

SELECT TUXSAMPLE.ICRWTPID, Avg(IIf([toc]=-999,0,[toc])) AS [plant mean TOC], [Plant Source Type, Last 12 Months].[Derived Source Type], Count(TUXWQP.TOC) AS CountOfTOC, TUXSAMPLE.EVNTNAME FROM ([Plant Source Type, Last 12 Months] INNER JOIN TUXSAMPLE ON [Plant Source Type, Last 12 Months].ICRWTPID = TUXSAMPLE.ICRWTPID) INNER JOIN TUXWQP ON TUXSAMPLE.EVENT_ID = TUXWQP.EVENT_ID WHERE (((TUXSAMPLE.SAMP_PER)>=7)) GROUP BY TUXSAMPLE.ICRWTPID, [Plant Source Type, Last 12 Months].[Derived Source Type], TUXSAMPLE.EVNTNAME HAVING (((Avg(IIf([toc]=-999,0,[toc]))) Is Not Null) AND ((Count(TUXWQP.TOC))>=9) AND ((TUXSAMPLE.EVNTNAME)="influent")) ORDER BY TUXSAMPLE.ICRWTPID;

Screened UV-254 INF

This query extracts all UV-254 values at the influent water point from plants with at least 9 of 12 months of data.

SELECT TUXSAMPLE.ICRWTPID, Avg(IIf([uv_254]=-999,0,[uv_254])) AS [plant mean UV_254], [Plant Source Type, Last 12 Months].[Derived Source Type], Count(TUXWQP.UV_254) AS CountOfUV_254, TUXSAMPLE.EVNTNAME FROM ([Plant Source Type, Last 12 Months] INNER JOIN TUXSAMPLE ON [Plant Source Type, Last 12 Months].ICRWTPID = TUXSAMPLE.ICRWTPID) INNER JOIN TUXWQP ON TUXSAMPLE.EVENT_ID = TUXWQP.EVENT_ID WHERE (((TUXSAMPLE.SAMP_PER)>=7)) GROUP BY TUXSAMPLE.ICRWTPID, [Plant Source Type, Last 12 Months].[Derived Source Type], TUXSAMPLE.EVNTNAME HAVING (((Avg(IIf([uv_254]=-999,0,[uv_254]))) Is Not Null) AND ((Count(TUXWQP.UV_254))>=9) AND ((TUXSAMPLE.EVNTNAME)="influent")) ORDER BY TUXSAMPLE.ICRWTPID;

B.3 Queries for DBP Plant Screening

Last 4 Quarters, average by quarter - TTHM & HAA5

This query builds off the query *Last 4 Quarters, by location & quarter - TTHM & HAA5*. It creates a data set with quarterly averages for TTHM and HAA5 for quarters with data for three of the four distribution system locations. See section 1.4.8 and 3.1.3 for further details.

SELECT [Last 4 Quarters, by location & quarter - TTHM & HAA5].ICRPWSID, [Last 4 Quarters, by location & quarter - TTHM & HAA5].ICRWTPID, [Last 4 Quarters, by location & quarter - TTHM & HAA5].SAMP_QTR, Count([Last 4 Quarters, by location & quarter - TTHM & HAA5].TTHM1) AS CountOfTTHM1, Avg([Last 4 Quarters, by location & quarter - TTHM & HAA5].TTHM1) AS AvgOfTTHM1, Avg([Last 4 Quarters, by location & quarter - TTHM & HAA5].HAA51) AS AvgOfTAA51, Sum(IIf([tthm1]>=40,1,0)) AS [Quarters > 40?], Sum(IIf([tthm1]>=60,1,0)) AS [Quarters > 60?], Sum(IIf([tthm1]>=75,1,0)) AS [Quarters > 75?], Sum(IIf([tthm1]>=80,1,0)) AS [Quarters > 80?], Sum(IIf([tthm1]>=100,1,0)) AS [Quarters > 100?], Sum(IIf([tthm1]>=120,1,0)) AS [Quarters > 102?], Sum(IIf([haa51]>=30,1,0)) AS [Quarters > 30?], Sum(IIf([haa51]>=45,1,0)) AS [Quarters > 45?], Sum(IIf([haa51]>=60,1,0)) AS [Quarters > 60?], Sum(IIf([haa51]>=75,1,0)) AS [Quarters > 60?], Sum(IIf([haa51]>=60,1,0)) AS [Quarters > 60?], Sum(IIf([haa51]>=75,1,0)) AS [Quarters > 60?], Sum(IIf([haa51]>=60,1,0)) AS [Quarters > 60?], Sum(IIf([haa51]>=75,1,0)) AS [Quarters > 75-HAA5?], Sum(IIf([haa51]>=90,1,0)) AS [Quarters > 90?] FROM [Last 4 Quarters, by location &

quarter - TTHM & HAA5] GROUP BY [Last 4 Quarters, by location & quarter - TTHM & HAA5].ICRPWSID, [Last 4 Quarters, by location & quarter - TTHM & HAA5].ICRWTPID, [Last 4 Quarters, by location & quarter - TTHM & HAA5].SAMP_QTR HAVING (((Count([Last 4 Quarters, by location & quarter - TTHM & HAA5].TTHM1))>=3)) ORDER BY [Last 4 Quarters, by location & quarter - TTHM & HAA5].ICRWTPID;

Last 4 Quarters, by location & quarter - TTHM & HAA5

This query is the first step in screening plants with the proper amount of DBP data. It creates a data set with only plant-months that have both TTHM and HAA5 at the four distribution system locations. See section 1.4.8 and 3.1.3 for further details.

SELECT TUXSAMPLE.ICRPWSID, TUXSAMPLE.ICRWTPID, TUXSAMPLE.SAMP_QTR, TUXSAMPLE.EVNTNAME, Avg(IIf([haa5]=-999,0,[haa5])) AS HAA51, Avg(IIf([tthm]=-999,0,[tthm])) AS TTHM1 FROM (TUXPLTMON INNER JOIN TUXSAMPLE ON (TUXPLTMON.SAMP_PER = TUXSAMPLE.SAMP_PER) AND (TUXPLTMON.ICRWTPID = TUXSAMPLE.ICRWTPID) AND (TUXPLTMON.ICRPWSID = TUXSAMPLE.ICRPWSID)) INNER JOIN TUXDBP ON TUXSAMPLE.EVENT_ID = TUXDBP.EVENT_ID WHERE (((TUXSAMPLE.SAMP_QTR)>=3)) GROUP BY TUXSAMPLE.ICRPWSID, TUXSAMPLE.ICRWTPID, TUXSAMPLE.SAMP_QTR, TUXSAMPLE.EVNTNAME HAVING (((TUXSAMPLE.EVNTNAME)="dse" Or (TUXSAMPLE.EVNTNAME)="avg" Or (TUXSAMPLE.EVNTNAME)="avg1" Or (TUXSAMPLE.EVNTNAME)="avg2" Or (TUXSAMPLE.EVNTNAME)="avg1" Or (TUXSAMPLE.EVNTNAME)="avg2" Or (TUXSAMPLE.EVNTNAME)="max") AND ((Avg(IIf([haa5]=-999,0,[haa5]))) IS NOT NUIL) AND ((Avg(IIf([tthm]=-999,0,[tthm]))) IS NOT NUIL)) ORDER BY TUXSAMPLE.ICRWTPID;

Last 4 Quarters, Plants min 3x3

This query builds off the query *Last 4 Quarters, average by quarter - TTHM & HAA5*. It creates a data set with yearly averages for TTHM and HAA5 for plants with three of four quarters of data. See section 1.4.8 and 3.1.3 for further details.

SELECT [Last 4 Quarters, average by quarter - TTHM & HAA5].ICRPWSID, [Last 4 Quarters, average by quarter - TTHM & HAA5].ICRWTPID, Count([Last 4 Quarters, average by quarter - TTHM & HAA5].ICRWTPID) AS CountOfICRWTPID FROM [Last 4 Quarters, average by quarter - TTHM & HAA5] GROUP BY [Last 4 Quarters, average by quarter - TTHM & HAA5].ICRWSID, [Last 4 Quarters, average by quarter - TTHM & HAA5].ICRWSID, [Last 4 Quarters, average by quarter - TTHM & HAA5].ICRWSID, [Last 4 Quarters, average by quarter - TTHM & HAA5].ICRWTPID HAVING (((Count([Last 4 Quarters, average by quarter - TTHM & HAA5].ICRWTPID))>=3)) ORDER BY [Last 4 Quarters, average by quarter - TTHM & HAA5].ICRWTPID;

Plants min 3x3, average by location - TTHM & HAA5

This query is used to extract the average TTHM and HAA5 data by location for plants screened by whether they meet the 3x3 criteria defined in sections 1.4.8 and 3.1.3.

SELECT [Plants min 3x3, by location & quarter - TTHM & HAA5].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5].EVNTNAME, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5].TTHM1) AS AvgOfTTHM1, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5].HAA51) AS AvgOfHAA51, Count([Plants min 3x3, by location & quarter - TTHM & HAA5].ICRPWSID) AS CountOfICRPWSID, Sum(IIf([tthm1]>=40,1,0)) AS [Quarters > 40?], Sum(IIf([tthm1]>=60,1,0)) AS [Quarters > 60?], Sum(IIf([tthm1]>=75,1,0)) AS [Quarters > 75?], Sum(IIf([tthm1]>=80,1,0)) AS

[Quarters > 80?], Sum(IIf([tthm1]>=100,1,0)) AS [Quarters > 100?], Sum(IIf([tthm1]>=120,1,0)) AS [Quarters > 120?], Sum(IIf([haa51]>=30,1,0)) AS [Quarters > 30?], Sum(IIf([haa51]>=45,1,0)) AS [Quarters > 45?], Sum(IIf([haa51]>=60,1,0)) AS [Quarters > 60-HAA5?], Sum(IIf([haa51]>=75,1,0)) AS [Quarters > 75-HAA5?], Sum(IIf([haa51]>=90,1,0)) AS [Quarters > 90?] FROM [Plants min 3x3, by location & quarter - TTHM & HAA5] GROUP BY [Plants min 3x3, by location & quarter - TTHM & HAA5].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5].EVNTNAME ORDER BY [Plants min 3x3, by location & quarter - TTHM & HAA5].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5].EVNTNAME ORDER BY [Plants min 3x3, by location & quarter - TTHM & HAA5].ICRWTPID;

Plants min 3x3, average by quarter - Other DBPs

This query is used to extract the average TOX, HAN4, CH, CP, DCP, and TCP data by quarter for plants screened by whether they meet the 3x3 criteria defined in sections 1.4.8 and 3.1.3.

SELECT [Plants min 3x3, by location & quarter - Other DBPs].ICRPWSID, [Plants min 3x3, by location & quarter - Other DBPs].ICRWTPID, [Plants min 3x3, by location & quarter - Other DBPs].TOX1) AS DPS].SAMP_QTR, Avg([Plants min 3x3, by location & quarter - Other DBPs].HAN4_1) AS AvgOfHAN4_1, Avg([Plants min 3x3, by location & quarter - Other DBPs].HAN4_1) AS AvgOfHAN4_1, Avg([Plants min 3x3, by location & quarter - Other DBPs].CH1) AS AvgOfCH1, Avg([Plants min 3x3, by location & quarter - Other DBPs].CH1) AS AvgOfCH1, Avg([Plants min 3x3, by location & quarter - Other DBPs].DCP1) AS AvgOfDCP1, Avg([Plants min 3x3, by location & quarter - Other DBPs].DCP1) AS AvgOfDCP1, Avg([Plants min 3x3, by location & quarter - Other DBPs].TCP1) AS AvgOfTCP1, Count([Plants min 3x3, by location & quarter - Other DBPs].ICRPWSID AS CountOfICRPWSID FROM [Plants min 3x3, by location & quarter - Other DBPs].WHERE ((([Plants min 3x3, by location & quarter - Other DBPs].EVNTNAME)<) "finish")) GROUP BY [Plants min 3x3, by location & quarter - Other DBPs].ICRWTPID, [Plants min 3x3, by location & quarter - Other DBPs].ICRWTPID, [Plants min 3x3, by location & quarter - Other DBPs].ICRWTPID, [Plants min 3x3, by location & quarter - Other DBPs].SAMP_QTR ORDER BY [Plants min 3x3, by location & quarter - Other DBPs].ICRWTPID;

Plants min 3x3, average by quarter - TTHM & HAA5

This query is used to extract the average TTHM and HAA5 data by quarter for plants screened by whether they meet the 3x3 criteria defined in sections 1.4.8 and 3.1.3.

SELECT [Plants min 3x3, by location & quarter - TTHM & HAA5].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5].SAMP_QTR, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5].TTHM1) AS AvgOfTTHM1, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5].HAA51) AS AvgOfHAA51, Count([Plants min 3x3, by location & quarter - TTHM & HAA5]. ICRPWSID) AS CountOfICRPWSID, Sum(IIf([tthm1]>=40,1,0)) AS [Quarters > 40?], Sum(IIf([tthm1]>=60,1,0)) AS [Quarters > 60?], Sum(IIf([tthm1] >= 75,1,0)) AS [Quarters > 75?], Sum(IIf([tthm1] >= 80,1,0)) AS[Quarters > 80?], Sum(IIf([tthm1]>=100,1,0)) AS [Quarters > 100?], Sum(IIf([tthm1]>=120,1,0)) AS[Quarters > 120?], Sum(IIf([has51]>=30,1,0)) AS [Quarters > 30?], Sum(IIf([has51]>=45,1,0)) AS[Quarters > 45?], Sum(IIf([haa51] >= 60,1,0)) AS [Quarters > 60-HAA5?], Sum(IIf([haa51] >= 75,1,0)) AS[Quarters > 75-HAA5?], Sum(IIf([haa51]>=90,1,0)) AS [Quarters > 90?] FROM [Plants min 3x3, by location & quarter - TTHM & HAA5] WHERE ((([Plants min 3x3, by location & quarter - TTHM & HAA5].EVNTNAME)<>"finish")) GROUP BY [Plants min 3x3, by location & quarter - TTHM & HAA5].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5].SAMP_QTR ORDER BY [Plants min 3x3, by location & quarter - TTHM & HAA5].ICRWTPID;

Plants min 3x3, by location & quarter - Other DBPs

This query is used to extract the plant-month TOX, HAN4, CH, CP, DCP, and TCP data by quarter and location. Plants screened by whether they meet the 3x3 criteria defined in sections 1.4.8 and 3.1.3.

SELECT TUXSAMPLE.ICRPWSID, TUXSAMPLE.ICRWTPID, TUXSAMPLE.SAMP_QTR, TUXSAMPLE.EVNTNAME, Avg(IIf([tox]=-999,0,[tox])) AS TOX1, Avg(IIf([han4]=-999,0,[han4])) AS HAN4_1, Avg(IIf([ch]=-999,0,[ch])) AS CH1, Avg(IIf([cp]=-999,0,[cp])) AS CP1, Avg(IIf([dcp_hk]=-999,0,[dcp_hk])) AS DCP1, Avg(IIf([tcp_hk]=-999,0,[tcp_hk])) AS TCP1, [Plant Source Type, Last 12 Months]. [Derived Source Type] FROM (([Plant Source Type, Last 12 Months] INNER JOIN ([Last 4 Quarters, Plants min 3x3] INNER JOIN TUXSAMPLE ON [Last 4 Quarters, Plants min 3x3].ICRWTPID = TUXSAMPLE.ICRWTPID) ON [Plant Source Type, Last 12] Months].ICRWTPID = TUXSAMPLE.ICRWTPID) INNER JOIN TUXDBP ON TUXSAMPLE.EVENT ID = TUXDBP.EVENT ID) INNER JOIN TUXWQP ON TUXSAMPLE.EVENT ID = TUXWQP.EVENT ID WHERE (((TUXSAMPLE.SAMP QTR)>=3)) GROUP BY TUXSAMPLE.ICRPWSID, TUXSAMPLE.ICRWTPID, TUXSAMPLE.SAMP QTR, TUXSAMPLE.EVNTNAME, [Plant Source Type, Last 12 Months].[Derived Source Type] HAVING (((TUXSAMPLE.EVNTNAME)="finish" Or (TUXSAMPLE.EVNTNAME)="dse" Or (TUXSAMPLE.EVNTNAME)="avg" Or (TUXSAMPLE.EVNTNAME)="avg1" Or (TUXSAMPLE.EVNTNAME)="avg2" Or (TUXSAMPLE.EVNTNAME)="max")) ORDER BY TUXSAMPLE.ICRWTPID:

Plants min 3x3, by location & quarter - TTHM & HAA5

This query is used to extract the plant-month TTHM and HAA5 data by quarter and location. Plants screened by whether they meet the 3x3 criteria defined in sections 1.4.8 and 3.1.3.

SELECT TUXSAMPLE.ICRPWSID, TUXSAMPLE.ICRWTPID, TUXSAMPLE.SAMP_QTR, TUXSAMPLE.EVNTNAME, [Plant Source Type, Last 12 Months].[Derived Source Type], Avg(IIf([haa5]=-999,0,[haa5])) AS HAA51, Avg(IIf([tthm]=-999,0,[tthm])) AS TTHM1 FROM ([Last 4 Quarters, Plants min 3x3] INNER JOIN (TUXSAMPLE INNER JOIN [Plant Source Type, Last 12 Months] ON TUXSAMPLE.ICRWTPID = [Plant Source Type, Last 12 Months].ICRWTPID) ON [Last 4 Quarters, Plants min 3x3].ICRWTPID = TUXSAMPLE.ICRWTPID) INNER JOIN TUXDBP ON TUXSAMPLE.EVENT_ID = TUXDBP.EVENT_ID WHERE (((TUXSAMPLE.SAMP_QTR)>=3)) GROUP BY TUXSAMPLE.ICRPWSID, TUXSAMPLE.ICRWTPID, TUXSAMPLE.SAMP_QTR, TUXSAMPLE.EVNTNAME, [Plant Source Type, Last 12 Months].[Derived Source Type] HAVING (((TUXSAMPLE.EVNTNAME)="finish" Or (TUXSAMPLE.EVNTNAME)="dse" Or (TUXSAMPLE.EVNTNAME)="avg" Or (TUXSAMPLE.EVNTNAME)="avg1" Or (TUXSAMPLE.EVNTNAME)="avg2" Or (TUXSAMPLE.EVNTNAME)="max") AND ((Avg(IIf([haa5]=-999,0,[haa5]))) Is Not Null) AND ((Avg(IIf([tthm]=-999,0,[tthm]))) Is Not Null)) ORDER BY TUXSAMPLE.ICRWTPID;

Plants min 3x3, max by quarter - TTHM & HAA5

This query is used to extract the RAA for TTHM and HAA5. Plants are screened by whether they meet the 3x3 criteria defined in sections 1.4.8 and 3.1.3.

SELECT [Plants min 3x3, by location & quarter - TTHM & HAA5].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5].SAMP_QTR, Max([Plants min 3x3, by location & quarter - TTHM & HAA5].TTHM1) AS

MaxOfTTHM1, Max([Plants min 3x3, by location & quarter - TTHM & HAA5].HAA51) AS MaxOfHAA51, Count([Plants min 3x3, by location & quarter - TTHM & HAA5].ICRPWSID) AS CountOfICRPWSID FROM [Plants min 3x3, by location & quarter - TTHM & HAA5] GROUP BY [Plants min 3x3, by location & quarter - TTHM & HAA5].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5].SAMP_QTR ORDER BY [Plants min 3x3, by location & quarter - TTHM & HAA5].ICRWTPID;

Plants min 3x3, Max-Min - TTHM & HAA5

This query is used to extract the maximum minus the minimum value for TTHM and HAA5. Plants are screened by whether they meet the 3x3 criteria defined in sections 1.4.8 and 3.1.3.

SELECT [Plants min 3x3, by location & quarter - TTHM & HAA5].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5].[Derived Source Type], Max([tthm1])-Min([tthm1]) AS [Max-Min TTHM], Max([haa51])-Min([haa51]) AS [Max-Min HAA5] FROM [Plants min 3x3, by location & quarter - TTHM & HAA5] GROUP BY [Plants min 3x3, by location & quarter - TTHM & HAA5].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5].[Derived Source Type];

B.4 Queries for Appendix A

Plants min 3x3, by location & quarter - HAA5 Speciation

This query is used to extract the plant-month HAA5 specie data by quarter and location. Plants screened by whether they meet the 3x3 criteria defined in sections 1.4.8 and 3.1.3.

SELECT TUXSAMPLE.ICRPWSID, TUXSAMPLE.ICRWTPID, TUXSAMPLE.SAMP_QTR, TUXSAMPLE.EVNTNAME, [Plant Source Type, Last 12 Months].[Derived Source Type], Avg(IIf([mcaa]=-999,0,[mcaa])) AS MCAA1, Avg(IIf([dcaa]=-999,0,[dcaa])) AS DCAA1, Avg(IIf([tcaa]=-999,0,[tcaa])) AS TCAA1, Avg(IIf([mbaa]=-999,0,[mbaa])) AS MBAA1, Avg(IIf([dbaa]=-999,0,[dbaa])) AS DBAA1 FROM ([Last 4 Quarters, Plants min 3x3] INNER JOIN (TUXSAMPLE INNER JOIN [Plant Source Type, Last 12 Months] ON TUXSAMPLE.ICRWTPID = [Plant Source Type, Last 12 Months].ICRWTPID) ON [Last 4 Quarters, Plants min 3x3].ICRWTPID = TUXSAMPLE.ICRWTPID) INNER JOIN TUXDBP ON TUXSAMPLE.EVENT_ID = TUXDBP.EVENT_ID WHERE (((TUXSAMPLE.SAMP_QTR)>=3)) GROUP BY TUXSAMPLE.ICRPWSID, TUXSAMPLE.ICRWTPID, TUXSAMPLE.SAMP_QTR, TUXSAMPLE.EVNTNAME, [Plant Source Type, Last 12 Months].[Derived Source Type] HAVING (((TUXSAMPLE.EVNTNAME)="finish" Or (TUXSAMPLE.EVNTNAME)="avg1" Or (TUXSAMPLE.EVNTNAME)="avg2" Or (TUXSAMPLE.EVNTNAME)="avg1" Or (TUXSAMPLE.EVNTNAME)="avg2" Or (TUXSAMPLE.EVNTNAME)="max")) ORDER BY TUXSAMPLE.ICRWTPID;

Plants min 3x3, by location & quarter - TTHM Speciation

This query is used to extract the plant-month TTHM specie data by quarter and location. Plants screened by whether they meet the 3x3 criteria defined in sections 1.4.8 and 3.1.3.

SELECT TUXSAMPLE.ICRPWSID, TUXSAMPLE.ICRWTPID, TUXSAMPLE.SAMP_QTR, TUXSAMPLE.EVNTNAME, [Plant Source Type, Last 12 Months].[Derived Source Type],

Avg(IIf([bdcm]=-999,0,[bdcm])) AS BDCM1, Avg(IIf([dbcm]=-999,0,[dbcm])) AS DBCM1, Avg(IIf([chcl3]=-999,0,[chcl3])) AS CHCL31, Avg(IIf([chbr3]=-999,0,[chbr3])) AS CHBR31 FROM ([Last 4 Quarters, Plants min 3x3] INNER JOIN (TUXSAMPLE INNER JOIN [Plant Source Type, Last 12 Months] ON TUXSAMPLE.ICRWTPID = [Plant Source Type, Last 12 Months].ICRWTPID) ON [Last 4 Quarters, Plants min 3x3].ICRWTPID = TUXSAMPLE.ICRWTPID) INNER JOIN TUXDBP ON TUXSAMPLE.EVENT_ID = TUXDBP.EVENT_ID WHERE (((TUXSAMPLE.SAMP_QTR)>=3)) GROUP BY TUXSAMPLE.ICRPWSID, TUXSAMPLE.ICRWTPID, TUXSAMPLE.SAMP_QTR, TUXSAMPLE.EVNTNAME, [Plant Source Type, Last 12 Months].[Derived Source Type] HAVING (((TUXSAMPLE.EVNTNAME)="finish" Or (TUXSAMPLE.EVNTNAME)="dse" Or (TUXSAMPLE.EVNTNAME)="avg" Or (TUXSAMPLE.EVNTNAME)="avg1" Or (TUXSAMPLE.EVNTNAME)="avg2" Or (TUXSAMPLE.EVNTNAME)="max") AND ((Avg(IIf([bdcm]=-999,0,[bdcm]))) Is Not Null) AND ((Avg(IIf([dbcm]=-999,0,[cbbr3]))) Is Not Null) AND ((Avg(IIf([chcl3]=-999,0,[chcl3]))) Is Not Null) AND ((Avg(IIf([chbr3]=-999,0,[chbr3]))) Is Not Null)) ORDER BY TUXSAMPLE.ICRWTPID;

Plants min 3x3, average by location - HAA5 Speciation

This query is used to extract the average HAA5 specie data by location for plants screened by whether they meet the 3x3 criteria defined in sections 1.4.8 and 3.1.3.

SELECT [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].EVNTNAME, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].MCAA1) AS AvgOfMCAA1, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].DCAA1) AS AvgOfDCAA1, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].TCAA1) AS AvgOfTCAA1, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].TCAA1) AS AvgOfTCAA1, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].MBAA1) AS AvgOfTCAA1, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].DBAA1) AS AvgOfDBAA1, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID) AS CountOfICRPWSID FROM [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWSID) AS CountOfICRPWSID FROM [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID;

Plants min 3x3, average by location - TTHM Speciation

This query is used to extract the average TTHM specie data by location for plants screened by whether they meet the 3x3 criteria defined in sections 1.4.8 and 3.1.3.

SELECT [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].EVNTNAME, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].BDCM1) AS AvgOfBDCM1, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].DBCM1) AS AvgOfDBCM1, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].CHCL31) AS AvgOfCHCL31, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].CHCL31) AS AvgOfCHCL31, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].CHBR31) AS AvgOfCHBR31, Count([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID) AS CountOfICRPWSID FROM [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID) AS CountOfICRPWSID FROM [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID;

Plants min 3x3, average by quarter - HAA5 Speciation

This query is used to extract the average HAA5 specie data by quarter for plants screened by whether they meet the 3x3 criteria defined in sections 1.4.8 and 3.1.3.

SELECT [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].SAMP_QTR, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].MCAA1) AS AvgOfMCAA1, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].DCAA1) AS AvgOfDCAA1, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].TCAA1) AS AvgOfDCAA1, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].TCAA1) AS AvgOfDCAA1, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].MBAA1) AS AvgOfMBAA1, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].DBAA1) AS AvgOfDBAA1, Count([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID) AS CountOfICRPWSID FROM [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID) AS CountOfICRPWSID FROM [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID, Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID; [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID; [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].

Plants min 3x3, average by quarter - TTHM Speciation

This query is used to extract the average TTHM specie data by quarter for plants screened by whether they meet the 3x3 criteria defined in sections 1.4.8 and 3.1.3.

SELECT [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].SAMP_QTR, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].BDCM1) AS AvgOfBDCM1, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].DBCM1) AS AvgOfBDCM1, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].DBCM1) AS AvgOfDBCM1, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].CHCL31) AS AvgOfDBCM1, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].CHCL31) AS AvgOfCHCL31, Avg([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].CHBR31) AS AvgOfCHBR31, Count([Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID) AS CountOfICRPWSID FROM [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].EVNTNAME)<"finish")) GROUP BY [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].EVNTNAME)<"finish")) GROUP BY [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRPWSID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID, [Plants min 3x3, by location & quarter - TTHM & HAA5 (w species)].ICRWTPID;

Plants min 3x3, RAA - HAA5 Speciation

This query is used to extract the RAA for AVG1, AVG2, DSE, and MAX distribution system sampling locations by HAA5 specie. Plants are screened by whether they meet the 3x3 criteria defined in sections 1.4.8 and 3.1.3.

SELECT [Plants min 3x3, average by quarter - HAA5 Speciation].ICRWTPID, [Plant Source Type, Last 12 Months].[Derived Source Type], Avg([Plants min 3x3, average by quarter - HAA5 Speciation].AvgOfMCAA1) AS AvgOfAvgOfMCAA1, Avg([Plants min 3x3, average by quarter - HAA5 Speciation].AvgOfDCAA1) AS AvgOfAvgOfAvgOfDCAA1, Avg([Plants min 3x3, average by quarter -

HAA5 Speciation].AvgOfTCAA1) AS AvgOfAvgOfTCAA1, Avg([Plants min 3x3, average by quarter - HAA5 Speciation].AvgOfMBAA1) AS AvgOfAvgOfMBAA1, Avg([Plants min 3x3, average by quarter - HAA5 Speciation].AvgOfDBAA1) AS AvgOfAvgOfDBAA1 FROM [Plants min 3x3, average by quarter - HAA5 Speciation] INNER JOIN [Plant Source Type, Last 12 Months] ON [Plants min 3x3, average by quarter - HAA5 Speciation].ICRWTPID = [Plant Source Type, Last 12 Months].ICRWTPID GROUP BY [Plants min 3x3, average by quarter - HAA5 Speciation].ICRWTPID = [Plant Source Type, Last 12 Months].[Derived Source Type];

Plants min 3x3, RAA - TTHM Speciation

This query is used to extract the RAA for AVG1, AVG2, DSE, and MAX distribution system sampling locations by TTHM specie. Plants are screened by whether they meet the 3x3 criteria defined in sections 1.4.8 and 3.1.3.

SELECT [Plants min 3x3, average by quarter - TTHM Speciation].ICRWTPID, [Plant Source Type, Last 12 Months].[Derived Source Type], Avg([Plants min 3x3, average by quarter - TTHM Speciation].AvgOfBDCM1) AS AvgOfAvgOfBDCM1, Avg([Plants min 3x3, average by quarter - TTHM Speciation].AvgOfDBCM1) AS AvgOfAvgOfDBCM1, Avg([Plants min 3x3, average by quarter - TTHM Speciation].AvgOfCHCL31) AS AvgOfAvgOfCHCL31, Avg([Plants min 3x3, average by quarter - TTHM Speciation].AvgOfCHBR31) AS AvgOfAvgOfCHCL31, Avg([Plants min 3x3, average by quarter - TTHM Speciation].AvgOfCHBR31) AS AvgOfAvgOfCHBR31 FROM [Plant Source Type, Last 12 Months] INNER JOIN [Plants min 3x3, average by quarter - TTHM Speciation] ON [Plant Source Type, Last 12 Months].ICRWTPID = [Plants min 3x3, average by quarter - TTHM Speciation].ICRWTPID GROUP BY [Plants min 3x3, average by quarter - TTHM Speciation].ICRWTPID, [Plant Source Type, Last 12 Months].[Derived Source Type];

Appendix C

Assessment of Data Quality Objectives

Exhibit C.1 Assessment of Data Quality Objectives for Existing Data Used in the Stage 2 DBPR Occurrence Document

Existing Data Source		Use in Stage 2 DBPR Occurrence Document	Level ¹	QA Plan? ²	Peer Reviewed?
1.	Information Collection Rule (ICR)	Used to characterize occurrence of disinfectants, disinfection byproducts (DBPs), and DBP precursors (e.g., total organic carbon[TOC]) in large surface water (SW) and ground water (GW) systems.	2	Yes	Yes
2.	ICR Supplemental Survey	Used to compare TOC occurrence in small, medium and large SW systems.	1	Yes	Yes
3.	National Rural Water Association (NRWA) Survey	Used to characterize operational characteristics, disinfection practices, DBP occurrence and occurrence of DBP precursors (e.g., TOC) for small SW systems. DBP and DBP precursor data were compared to that of large systems. Used to assess variability in TTHM and HAA5 occurrence in distribution systems of small SW systems.	1	Yes	No
4.	Water Utility Survey (WATER:\STATS database)	Used to compare operational characteristics, disinfection practices, DBP occurrence, and DBP precursor occurrence of medium and large SW systems and medium and large ground water GW systems	1	Yes	Yes
5.	Ground Water Supply Survey	Used to compare TOC occurrence between small, medium, and large GW systems	1	Yes	No
6.	State Data	Used to compare TTHM occurrence on small GW systems to occurrence in large GW systems.	1	No	No

Notes:

¹ Level 1 data are those data that provide background information or context for a particular assessment or discussion, but are not deemed to be influential in EPA's decision-making process. Level 2 data are those data that are deemed to be highly important or influential in EPA's decision-making process. Refer to the *Work Assignment 1-05 Project-Specific Supplement to the Programmatic Quality Assurance Project Plan* (USEPA 2003d) for additional information on level designations.

² See Sections 1.4 and 1.5 for a description of QA plans and/or peer review processes for each existing data source shown.