1. INTRODUCTION

1.1 Objective of this Manual

Chlorine is, by far, the most commonly used disinfectant in the drinking water treatment industry (Sawyer et al., 1994). Today, chlorine is used as a primary disinfectant in the vast majority of all surface water treatment plants, being used as a pre-disinfectant in more than 63 percent and as a post-disinfectant in more than 67 percent of all surface water treatment plants (USEPA, 1997). This manual is organized to provide technical data and engineering information on disinfectants that are not as widely used as chlorine. Also, where applicable, this document describes the use of these disinfectants as oxidants and any associated implications.

The U.S. Environmental Protection Agency (EPA) encourages utilities to examine all aspects of their current disinfection practices to identify opportunities to improve the quality of the finished water without reducing microbial protection. The objective of this guidance manual is to describe alternative disinfectants and disinfection techniques that may be used to comply with both the Stage 1 Disinfectants and Disinfection Byproducts Rule (DBPR) and Interim Enhanced Surface Water Treatment Rule (IESWTR) and highlight advantages and disadvantages of their use.

EPA is not recommending that utilities employ the disinfectants and oxidants discussed in this manual, nor is it advocating that utilities switch from one disinfectant or oxidant to another. EPA acknowledges that selection of the most appropriate disinfection technique is a site-specific decision best left to utility personnel and state agencies. Utilities should use this guidance as an information resource to assist in the selection of appropriate disinfectants and disinfectant schemes to meet their specific goals. Extensive bench and/or pilot scale testing and a thorough review of regulatory requirements should precede changes to disinfection practice. Systems should refer to the Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Works Systems Using Surface Water Sources (AWWA, 1991) to ensure disinfectant schemes meet regulatory log inactivation requirements. Utilities should also refer to EPA's *Disinfection Profiling and Benchmarking Guidance Manual* (currently in production) to ensure compliance with the new regulatory requirements of the IESWTR.

This chapter presents a brief discussion of the background and regulatory context of alternative disinfectants, including an overview of the disinfection profiling and benchmarking approach to evaluate disinfection efficiency. In addition, a decision-making framework is provided that utilities can employ to assess the applicability of various disinfectants and disinfection strategies for individual systems. Chapter 2 presents an overview of disinfection, including the use of chlorine, with the next six chapters of this manual devoted to each of the following alternative disinfectants and oxidants:

- ***Chapter 3*** - Ozone (O_3);
- ***Chapter 4*** - Chlorine dioxide (ClO_2);
- ***Chapter 5*** - Potassium permanganate ($KMnO_4$);
- ***Chapter 6*** - Chloramine (NH_2Cl);
- ***Chapter 7*** - Ozone/hydrogen peroxide combinations (O_3/H_2O_2); and
- ***Chapter 8*** - Ultraviolet radiation (UV).

For each disinfectant, this guidance manual describes the chemistry specific to the disinfection or oxidation process, generation, primary uses and points of application, disinfection byproduct (DBP) formation, pathogen inactivation and disinfection efficacy, the status of analytical methods for residual monitoring, and operational considerations. Chapter 9 provides similar information regarding the use of combined disinfectants. A summary of existing disinfectant usage in the United States is provided in Appendix A. Cost estimates for the use of alternative disinfectants are provided in Appendix B.

1.2 Background

The most important use of disinfectants in water treatment is to limit waterborne disease and inactivate pathogenic organisms in water supplies. The first use of chlorine as a continuous process in water treatment was in a small town in Belgium in the early 1900s (White, 1992). Since introduction of filtration and disinfection at water treatment plants in the United States, waterborne diseases such as typhoid and cholera have been virtually eliminated. For example, in Niagara Falls, NY between 1911 and 1915, the number of typhoid cases dropped from 185 deaths per 100,000 population to nearly zero following introduction of filtration and chlorination (White, 1986).

In 1974, researchers in the Netherlands and the United States demonstrated that trihalomethanes (THMs) are formed as a result of drinking water chlorination (Rook, 1974; Bellar et al., 1974). THMs are formed when chlorine or bromide reacts with organic compounds in the water. EPA subsequently conducted surveys confirming widespread occurrence of THMs in chlorinated water supplies in the United States (Symons et al., 1975; USEPA, 1978). THMs and other DBPs have been shown to be carcinogenic, mutagenic, etc. These health risks may be small, but with the large population exposed, need to be taken seriously.

As a result of DBP concerns from chlorine, EPA, as well as the water treatment industry, placed more emphasis on the use of disinfectants other than chlorine. Some of these alternative disinfectants, however, have also been found to produce DBPs as a result of either reactions between disinfectants and compounds in the water or as a natural decay product of the disinfectant itself (McGuire et al., 1990; Legube et al; 1989). These DBPs include:

- Halogenated organics, such as THMs, haloacetic acids, haloketones, and others, that are produced primarily as a result of chlorination.

- Organic oxidation byproducts such as aldehydes, ketones, assimilable organic carbon (AOC), and biodegradable organic carbon (BDOC), that are associated primarily with strong oxidants such as ozone, chlorine, and advanced oxidation; and
- Inorganics such as chlorate and chlorite, associated with chlorine dioxide, and bromate, that is associated with ozone, and has also has been found when chlorine dioxide is exposed to sunlight.

As documented in this manual, the type and amount of DBPs produced during treatment depends largely on disinfectant type, water quality, treatment sequences, contact time, and environmental factors such as temperature and pH.

When considering the use of alternative disinfectants, systems should ensure that the inactivation of pathogenic organisms is not compromised. Pathogens pose an immediate critical public health threat due to the risk of an acute disease outbreak. Although most identified public health risks associated with DBPs are chronic, long-term risks, many systems will be able to lower DBP levels without compromising microbial protection.

1.3 Regulatory Context

Pursuant to requirements of the Safe Drinking Water Act (SDWA) Amendments of 1996, EPA is developing interrelated regulations to control microbial pathogens and disinfectant residuals and disinfection byproducts in drinking water. These rules are collectively known as the microbial/disinfection byproducts (M-DBP) rules and are intended to address complex risk trade-offs between the desire to inactivate pathogens found in water and the need to reduce chemical compounds formed as byproducts during disinfection. The rules are being promulgated in two phases.

As part of the first phase, the Stage 1 DBPR and the IESWTR were promulgated on December 16, 1998 (63 FR 69390 and 63 FR 69478, respectively). The Stage 1 DBPR applies to all community water systems (CWS) and non-transient, non-community water systems (NTNCWS) that treat their water with a disinfectant for either primary or residual treatment. The IESWTR amends the Surface Water Treatment Rule (SWTR) and includes new and more stringent requirements to control waterborne pathogens including specifically the protozoan *Cryptosporidium*. The IESWTR applies to all public water systems that use surface water, or ground water under the direct influence of surface water as defined at 40 CFR, Part 141, Subpart H[1], and that serve at least 10,000 people.

Three future rules, also included in phase one include the Long-Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR), the Ground Water Rule (GWR), and the Filter Backwash Rule (FBR). Each of these rules are planned for promulgation in November 2000. The LT1ESWTR will address pathogen inactivation and removal requirements for Subpart H systems serving fewer than 10,000 people. The GWR will specify appropriate disinfection techniques, including the use of best

[1] Subpart H systems are defined as public water systems supplied by a surface water source or by a ground water source under the direct influence of surface water.

management practices (BMPs) and source control measures. The FBR will set a standard for filter backwash recycling for all public water systems regardless of size.

The second phase, consisting of the Stage 2 DBPR and the Long-Term 2 ESWTR, will be promulgated in the year 2002 and will revisit the regulations for the formation of DBPs for all systems and the inactivation and removal of pathogens for surface water systems, respectively.

The projected dates for future M-DBP regulatory activities are summarized in Table 1-1.

Table 1-1. Key Dates for Regulatory Activities

Date	Regulatory Action
November 2000	Promulgate Long-Term 1 Enhanced Surface Water Treatment Rule
November 2000	Promulgate Ground Water Rule
November 2000	Promulgate Filter Backwash Rule
May 2002	Promulgate Stage 2 Disinfectants and Disinfection Byproduct Rule
May 2002	Promulgate Long-Term 2 Enhanced Surface Water Treatment Rule

Concurrent with the M-DBP rules, in May 1996, EPA promulgated the Information Collection Rule (ICR) to obtain data on source water quality, byproduct formation, and drinking water treatment plant design and operations. The ICR applies to Subpart H systems serving more than 100,000 people and ground water systems serving more than 50,000 people. EPA intended to use data from the ICR to address completely the complex trade-offs between chronic DBP health risks and acute pathogenic health risks, but delays in promulgation of the ICR eliminated this potential data source for use in the IESWTR. Until the ICR data are analyzed in detail, EPA cannot fully address the issue of DBP and pathogenic risk trade-offs.

National Primary and Secondary Drinking Water Regulations, published in 40 CFR Parts 141 and 143, respectively, limit the amount of specific contaminants and residual disinfectants and classes of these compounds that are delivered to users of public water systems. These limits are expressed as follows:

- **Maximum Contaminant Level Goals (MCLGs).** MCLGs are non-enforceable health goals for public water systems. MCLGs are set at levels that, in the EPA Administrator's judgment, allow no known or anticipated adverse effect on the health of persons to occur and that allow an adequate margin of safety.
- **Maximum Residual Disinfectant Level Goals (MRDLGs).** As with MCLGs, EPA has established MRDLGs for disinfectants at levels at which no known or anticipated adverse effects on the health of persons occur and that allow an adequate margin of safety. MRDLGs are non-enforceable health goals based only on health effects and exposure information and do not reflect the benefit of the addition of the chemicals for control of waterborne microbial contaminants.

- **Maximum Contaminant Levels (MCLs).** MCLs are enforceable standards set as close to the MCLGs as technically and economically feasible.
- **Maximum Residual Disinfectant Levels (MRDLs).** MRDLs are similar to MCLs. MRDLs are enforceable standards, analogous to MCLs, that recognize the benefits of adding a disinfectant to water on a continuous basis and of addressing emergency situations such as distribution system pipe ruptures. As with MCLs, EPA has set the MRDLs as close to the MRDLGs as feasible.

In November 1979, the EPA set an interim MCL for Total THMs (TTHMs) of 0.10 mg/L as an annual average for systems serving at least 10,000 people. This standard was based on the need to reduce THM levels due to suspected carcinogenicity. Since then, EPA has developed and promulgated standards for numerous contaminants. As of the December 16, 1998 DBPR promulgation, MCLGs, MCLs, MRDLGs, and MRDLs are as presented in Tables 1-2 through 1-4. As included in these tables, the December 16, 1998 Stage 1 DBPR:

- Lowered the existing MCL for TTHMs from 0.10 mg/L to 0.080 mg/L;
- Extended the MCL for TTHMs to all size systems;
- Requires enhanced coagulation or enhanced precipitative softening for certain systems;
- Established MRDLs and MRDLGs for chlorine, chloramine, and chlorine dioxide;
- Established MCLs for haloacetic acid (five) (HAA5), bromate, and chlorite, and
- Established MCLGs for eight disinfection byproducts.

Further, the SWTR of 1989 requires 3.0-log inactivation for *Giardia* cysts and 4.0-log inactivation for viruses in surface water supplies. To meet these goals, the SWTR established treatment requirements for filtration and disinfection. As shown in Table 1-5, these goals can be met using various treatment schemes that include filtration and disinfection. The IESWTR requires a 2.0 log removal of *Cryptosporidium* for Subpart H systems serving at least 10,000 people.

Table 1-2. Primary Drinking Water Regulations Related to Microbiological Contaminants

Compound	MCLG (mg/L)	MCL (mg/L)	Potential Health Effects	Sources of Drinking Water Contamination
Giardia lamblia	Zero	TT[1]	Gastroenteric disease	Human and animal fecal waste
Legionella	Zero	TT	Legionnaire's disease	Common bacteria in natural waters; can proliferate in water heating systems
Heterotrophic Plate Count	N/A	TT	Indicates water quality, effectiveness of treatment	
Total Coliform	Zero	< 5.0%[2]	Indicates potential presence of gastroenteric pathogens	Human and animal fecal waste
Turbidity	N/A	TT	Indicates water treatment failure and pathogens in drinking water	Particles from storm runoff, discharges into source water, and erosion
Viruses	Zero	TT	Gastroenteric disease	Human and animal fecal waste

Source: AWWA Internet, 1997.

[1] TT = Treatment technique requirement in lieu of MCL as established in 40 CFR §141.70.

[2] No more than 5.0 percent positive if >40 samples/month. No more than 1 positive if <40 samples/month [40 CFR §141.63(a)].

Table 1-3. Primary Drinking Water Regulations Related to Disinfection Byproducts

Compound	MCLG (mg/L)	MCL (mg/L)	Potential Health Effects	Sources of Drinking Water Contamination
Bromate	Zero[3]	0.010[4]	Cancer	Ozonation byproduct
Bromodichloromethane	Zero[3]	see TTHMs	Cancer, liver, kidney, and reproductive effects	Drinking water chlorination and chloramination byproduct
Bromoform	Zero[3]	see TTHMs	Cancer, nervous system, liver and kidney effects	Drinking water ozonation, chloramination, and chlorination byproduct
Chlorite	0.8[3]	1.0[4]	Hemolytic anemia	Chlorine dioxide disinfection byproduct
Chloroform	Zero[3]	see TTHMs	Cancer, liver, kidney, reproductive effects	Drinking water chlorination and chloramination byproduct
Dibromochloromethane	0.06[3]	see TTHMs	Nervous system, liver, kidney, reproductive effects	Drinking water chlorination and chloramination byproduct
Dichloroacetic Acid	Zero[3]	See HAA5	Cancer and other effects	Drinking water chlorination and chloramination byproduct
Haloacetic Acids[1] (HAA5)	N/A	0.060[4]	Cancer and other effects	Drinking water chlorination and chloramination byproduct
Trichloroacetic Acid	0.3[3]	See HAA5	Possibly cancer and reproductive effects	Drinking water chlorination and chloramination byproduct
Total Trihalomethanes[2] (TTHMs)	N/A	0.08[4]	Cancer and other effects	Drinking water chlorination and chloramination byproduct

Source: 63 *FR* 69390 (12/16/98)

[1] HAA5 is the sum of the concentrations of mono-, di-, and trichloroacetic acids and mono-and dibromoacetic acids.

[2] Total Trihalomethanes are the sum of the concentrations of bromodichloromethane, dibromochloromethane, bromoform, and chloroform.

[3] Finalized on December 16, 1998 (63 FR 69390) as established in 40 CFR §141.53.

[4] Finalized on December 16, 1998 (63 FR 69390) as established in 40 CFR §141.64

Table 1-4. Primary Drinking Water Regulations Related to Residual Disinfectants

Disinfectant	MRDLG[3] (mg/L)	MRDL[4] (mg/L)
Chlorine[1]	4 (as Cl_2)	4.0 (as Cl_2)
Chloramine[2]	4 (as Cl_2)	4.0 (as Cl_2)
Chlorine Dioxide	0.8 (as ClO_2)	0.8 (as ClO_2)

[1] Measured as free chlorine
[2] Measured as total chlorine
[3] Finalized on December 16, 1998 (63 *FR* 69390) as established in 40 CFR §141.54.
[4] Finalized on December 16, 1998 (63 *FR* 69390) as established in 40 CFR §141.65

Table 1-5. Log Removal/Inactivation through Filtration and Disinfection Required Under the SWTR

Process	*Giardia* cysts	Virus
Total log removal/inactivation Required	***3.0***	***4.0***
Conventional sedimentation/filtration credit	2.5	2.0
Disinfection inactivation required	0.5	2.0
Direct filtration credit	2.0	1.0
Disinfection inactivation required	1.0	3.0
Slow sand filtration credit	2.0	2.0
Disinfection inactivation required	1.0	2.0
Diatomaceous earth credit	2.0	1.0
Disinfection inactivation required	1.0	3.0
No Filtration	0.0	0.0
Disinfection inactivation required	3.0	4.0

Source: AWWA, 1991.
Note: Some instances may require higher than 3 and 4 log removal. Also, some states may reduce removal filtration process.

1.3.1 Disinfection Profiling and Benchmarking

The IESWTR establishes disinfection benchmarking as a procedure requiring certain PWSs to evaluate the impact on microbial risk of proposed changes in disinfection practice. It is designed to facilitate utilities and States working together to assure that pathogen control is maintained while the provisions of the Stage 1 DBPR are implemented. This procedure involves a PWS charting daily levels of pathogen inactivation for a period of at least one year to create a profile of inactivation performance. The PWS then uses this profile to determine a baseline or benchmark of inactivation against which proposed changes in disinfection practices can be measured.

Systems are required to prepare a disinfection profile if either TTHM or HAA5 levels are at least 0.064 or 0.048 mg/L, respectively, as an annual average. These levels, equal to 80 percent of the MCLs established for these compounds by the Stage 1 DBPR, are intended to include most systems that will modify their disinfection practices to comply with the Stage 1 DBPR. To determine applicability, systems that collected TTHM and HAA5 data under the ICR must use the results of the

last 12 months of ICR monitoring unless the State determines there is a more representative data set. Non-ICR systems may use existing TTHM and HAA5 data, if approved by the State, or must conduct TTHM and HAA5 monitoring for four quarters. This monitoring must be completed no later than 15 months after promulgation of the IESWTR (i.e., by March, 2000). Alternatively, systems can elect to forgo this monitoring if they construct a disinfection profile.

A disinfection profile consists of a compilation of daily *Giardia lamblia* log inactivations (plus virus inactivations for systems using either chloramines or ozone for primary disinfection) computed over a period of at least one year. It is based on daily measurements of disinfectant residual concentration(s), contact time(s), temperature, and pH. The profile may be developed using up to 3 years of existing (i.e. grandfathered) data, if the State finds the data acceptable. Systems having less than 3 years of acceptable grandfathered data are required to conduct one year of monitoring to create the profile. This monitoring must be complete within 27 months of IESWTR promulgation (i.e., by March, 2001). The disinfection benchmark is equal to the lowest monthly average inactivation level in the disinfection profile (or average of low months for multi-year profiles).

Any system required to develop a disinfection profile under the IESWTR that decides to make a significant change to its disinfection practice must consult with the State prior to making the change. Significant changes in disinfection practice are defined as: 1) moving the point of disinfection, not including routine seasonal changes, 2) changing the type of disinfectant, 3) changing the disinfection process, and 4) other modifications designated as significant by the State. As part of the consultation process, the system must submit to the State the following information: a description of the proposed change; the disinfection profile for Giardia lamblia (and, if necessary, viruses) and benchmark; and an analysis of how the proposed change will affect the current levels of disinfection. In addition, the State is required to review the disinfection profile a part of its periodic sanitary survey.

For more information on disinfection profiling and benchmarking, refer to EPA's *Disinfection Profiling and Benchmarking Guidance Manual* (expected to be available in 1999).

1.4 Use of Disinfectants as Chemical Oxidants

Most disinfectants are strong oxidants and/or generate oxidants as byproducts (such as hydroxyl free radicals) that react with organic and inorganic compounds in water. While the primary focus of this manual is disinfection, many of the disinfectants described in this manual are also used for other purposes in drinking water treatment, such as taste and odor control, improved flocculation, and nuisance control. Because DBPs are produced irrespective of the intended purpose of the oxidant, it is important to also address uses of disinfectants as oxidants in water treatment. These additional uses are described in more detail in Chapter 2.

1.5 How Chlorine is Addressed in this Guidance Manual

This guidance manual does not provide as broad a discussion of chlorine and chlorination practices as it does for the capabilities and uses of alternative disinfectants. There are two reasons EPA has

taken this approach: 1) the goal of this manual is to provide technical and engineering information to utilities and the states on alternative disinfectants and oxidants, about which there is less comprehensive information than for chlorine; and 2) a great majority of utilities already use chlorine, in a wide variety of applications, for which there exists a wealth of literature on chlorine's uses and performance capabilities. Summarizing this large body of knowledge in this guidance is neither practical nor necessary.

This manual is not an EPA endorsement of alternative disinfectants nor is it a recommendation for utilities to switch from chlorine to an alternative disinfectant. Rather, this manual provides technical and engineering information to assist local professionals in making treatment decisions. EPA believes that utility and state program personnel are best able to select disinfectants and design a disinfection scheme, based upon site-specific conditions, that meets operational and regulatory constraints. EPA does not require the use of chlorine or any other specific disinfectant for site-specific uses. Again, local professionals are best suited to select disinfectants to address the unique water treatment challenges posed by their source water and plant infrastructure.

EPA recognizes that, at the present time, chlorination is an important and central component of most water treatment regimes in this country. As such, a summary of the uses and capabilities of chlorine is provided in Section 2.7 of this manual. Section 2.7 also contains an extensive reference list for additional information on chlorination.

1.6 A Summary of Alternative Disinfectant Properties

Subsequent chapters in this manual discuss several disinfectant alternatives available to a water supplier. Table 1-6 summarizes the key technical and regulatory considerations associated with the use of the various disinfectants for selecting the most appropriate disinfectant. The table provides some broad guidelines to provide a framework for decision making. The ratings in Table 1-6 are based on a typical disinfectant application. Thus, even though chlorine is considered to be prone to THM formation, the table does not address the degree or amount of THMs produced. Similarly, more than 2-log inactivation can be achieved for some disinfectants, but the high dose required may not make it a reasonable application, and in that case, would be identified in the table as not able to achieve 2-log inactivation.

The following key issues are addressed in Table 1-6:

- **THMs, oxidized organics, and halogenated organics are produced.** Halogenated organics are formed when chlorine or ozone (in the presence bromide ion) is used, while oxidized organics occur in the greatest concentration when a strong oxidant is used. The production of DBPs depends on the amounts and types of precursors in the water.
- **Inorganic byproducts are produced.** Inorganic byproducts include chlorate ion, chlorite ion, and bromate ion associated with chlorine dioxide and ozone.

- **MRDLs are required for some disinfectants.** Note that this requirement must be balanced with the requirement to maintain a residual in the distribution system. For most disinfectants, such as chlorine, the MRDL is relatively high and will generally not create a problem.
- **Lime softening impacts are noted.** The high pH treatment during lime softening has an impact on chlorine, chloramines, and UV.
- **Turbidity impacts UV disinfection and ozonation.** Ozone may interfere with coagulation and settling. As such, it is recommended that ozonation be placed after settling but before filters to minimize turbidity impacts.
- **Inactivation requirements are divided into those achieving more or less than 2-log inactivation.** This differentiation is to identify the feasibility of achieving high inactivation at modest doses. For example, while chlorine can achieve 3-log *Giardia* cyst inactivation, the CT requirement for 3-log inactivation of 100 to more than 300 mg-min/L will require high chlorine doses and/or long contact times. However, 4-log virus inactivation is achievable with a CT of 15 to 60 mg·min/L for most temperatures.

  Recently there has been some reports of 2-log and higher *Cryptosporidium* oocyst inactivation with UV, using a system that concentrates the oocysts on a filter and then allows extended exposure to UV to doses as high as 8,000 $mW \cdot s/cm^2$. This type application is considered experimental at this time.
- **Applicability as a secondary disinfectant represents the ability of the disinfectant to maintain a residual in the distribution system.** Only chlorine, chlorine dioxide, and monochloramine provide residual disinfection in the distribution system. Chlorine dioxide is limited to systems with smaller distribution systems because the total chlorine dioxide dose that can be applied is limited by the production of chlorate ion and chlorite ion.
- **Operator skill provides general guidance to the amount of operator attention and maintenance required.** All of the disinfectants can be placed on automatic control to limit the amount of operator attention. The operational attention is rated based on the complexity of the disinfectant application. Therefore, permanganate, which is a simple chemical feed system with few mechanical elements, is rated 1 (low attention), while peroxone which include both ozone systems and hydrogen peroxide feed systems, is rated 5 (high attention).
- **All chemical disinfectants are judged to be applicable to small and large utilities.** Modular units of the technologies can cover a large range of flows. Ozone and chlorine dioxide generators are available with small and large capacities. Chlorine and chemical feed systems have been used successfully in all applications. Most UV water treatment facilities are less than 200 gpm in capacity.

Key elements in the decision making process relate to the water source (i.e., ground or surface water) and existing treatment configuration (including filtration) because these factors have a significant impact on the degree of log removal required during disinfection. Water quality has a large impact on the potential for DBP BOM formation.

Table 1-6. Summary of Disinfectant Properties

(Based on Typical Disinfectant Application)

Condition	Chlorine	Ozone	Chlorine Dioxide	Permanganate	Chloramine	Ozone/Peroxide	Ultraviolet
Produce THM with TOC	y	s	n	n	y	s	n
Produce oxidized organics	s	y	s	s	n	y	s
Produce halogenated organics	y	s	n	n	y	s	n
Produce inorganic byproducts	n	s	y	n	n	s	n
Produce BOM	s	y	s	n	n	y	n
MRDL applies	y	n	y	n	y	n	n
Lime softening impacts	y	n	n	n	y	n	y
Turbidity impacts	n	s	n	n	n	s	y
Meet *Giardia* - <2.0 log	y	y	y	n	n	n	n
Meet *Giardia* - >2.0 log	n	y	y	n	n	n	n
Meet *Crypto* - <2.0 log	n	y	y	n	n	n	n
Meet *Crypto* - >2.0 log	n	y	n	n	n	n	n
Meet Virus - <2.0 log	y	y	y	n	n	n	y
Meet Virus - >2.0 log	y	y	y	n	n	n	y
Secondary disinfectant	y	n	s	n	y	n	n
Operator skill (1=low; 5=high)	1	5	5	1	2	5	3
Applicable to large utilities	y	y	y	y	y	y	n
Applicable to small utilities	y	y	y	y	y	y	y

y = yes, n = no, s = sometimes

The following sections describe each of these phases.

1.7 Selecting a Disinfection Strategy

This section presents general guidance that can be used to assess the applicability of various disinfectants or combination of disinfectants to select an appropriate disinfection strategy. Because the selection of an appropriate strategy depends on site-specific conditions unique to each water supply system, final selection of a strategy should be made with appropriate technical guidance (e.g., engineering study/evaluation or bench or pilot scale testing of alternatives). Selecting the most appropriate disinfectant strategy for water treatment requires a balance among three key driving forces:

- **Providing water free of pathogens.** Since the SWTR, the regulatory focus for pathogen removal focused on coliform bacteria, heterotrophic plate counts, *Giardia* cysts, *Legionella*, and viruses. Recently, the focus has been expanded to include *Cryptosporidium* oocyst removal and inactivation, especially due to its resistance to chlorine.

- **Avoiding the production of disinfection byproducts (DBPs).** Trihalomethanes (THMs), other halogenated organics, ozone DBPs, oxidation byproducts, and some disinfectant residuals present a health risk and must be limited in drinking waters. DBP precursor removal through process optimization or enhanced coagulation is the first step in DBP control.
- **Requiring residual disinfectant to maintain the bacteriological quality in the water as it is distributed to customers to control regrowth.** The potential for DBP formation increases with extended contact between DBP precursors and residual disinfectants.

When changing disinfectants or oxidants water providers should consult with their primacy agencies. The impact of the change should consider the impact on disinfection credit using disinfection profiling and benchmarking techniques as summarized in Section 1.3.

1.7.1 Disinfection Strategy Evaluation

The selection of a disinfection strategy, as presented below, is affected by the following:

- Effectiveness of the current disinfection system;
- Need to change disinfectants;
- Selection of an alternative disinfectant; and
- Primary and secondary disinfection requirements.

As used in this guidance, primary and secondary disinfection are defined as follows:

Primary disinfection: The first (i.e., primary) disinfectant used in a treatment system, with the primary objective of the disinfectant being to achieve the necessary CT (i.e., microbial inactivation).

Secondary disinfection: The second disinfectant used in a treatment system, with the primary objective of the disinfectant being to maintain the disinfection residual through the distribution system.

For discussion, the approach to select a disinfection strategy is divided into three phases:

- Evaluate the current primary disinfection practice
- Select a primary disinfectant
- Select a secondary disinfectant.

1.7.1.1 Evaluate the Current Primary Disinfection Practice

Figure 1-1 presents the decision making process used to determine whether the present primary disinfectant can meet disinfection and byproduct requirements. The key decision points in Figure 1-1 include:

- **Meet current microbial inactivation limits.** Microbial limits are defined by the primary drinking water standards shown in Table 1-2. The regulated indicators of pathogens include

Giardia lamblia, *Legionella*, HPC, total coliform turbidity, and viruses. The disinfectant must be capable of meeting the inactivation requirements for disinfection. If not, the plant must determine if the current disinfectant can meet the microbial inactivation requirements solely through process modifications. A process modification may be to move the application point, increase dose, increase contact time, or adjust pH. If not, a new disinfectant may be needed. In some instances, a PWS may opt to improve its current microbial inactivation even though the PWS is meeting current microbial limitations. In these instances, an evaluation is necessary to ensure that any process modifications to improve inactivation will still provide compliance with the microbial limits.

- **Meet current DBP limits.** A second set of limits imposed on disinfectant usage are DBP requirements. The DBP limits are established in the Stage 1 DBP rule (See Table 1-3 and Table 1-5). To meet these limits on a consistent basis under normal varying water quality conditions, 80 percent of the MCL serves as an action level that requires a change in treatment practice. Similar to microbial inactivation, some PWSs may desire to improve current DBP protection, thus requiring evaluation of these modifications. By optimizing existing treatment processes, the production of DBPs can be reduced. Optimization may include pretreatment optimization (i.e., coagulation, filtration, etc.) or process modifications such as moving the point of disinfection. Enhanced coagulation is required by the Stage 1 DBP rule. Where process modifications are contemplated, the PWS must ensure that both microbial inactivation and DBP formation comply with applicable regulatory requirements. If optimized treatment cannot meet DBP and microbial requirements, a new disinfectant may be needed.

1.7.1.2 Select a Primary Disinfectant

If it is determined that a new disinfectant is required or desired for better public health protection, the second phase in the decision process (Figure 1-2) addresses the factors concerning selection of a primary disinfectant. This decision requires knowledge of the following three key components:

- **TOC concentration.** A high TOC concentration indicates a high potential for DBP formation. In these cases, the decision tree will favor those disinfectants that will not produce DBPs or will produce the least amount of DBPs. Note that precursor removal and enhanced coagulation are used to reduce TOC during treatment optimization as indicated in Figure 1-1. "High TOC" quantifies the potential to produce DBPs and is defined as a condition meeting one of the following criteria:
  - TOC exceeds 2 mg/L;
  - TTHM exceeds MCL (0.08 mg/L under Stage 1 DBPR); or
  - HAA5 exceeds MCL (0.06 mg/L under Stage 1 DBPR).

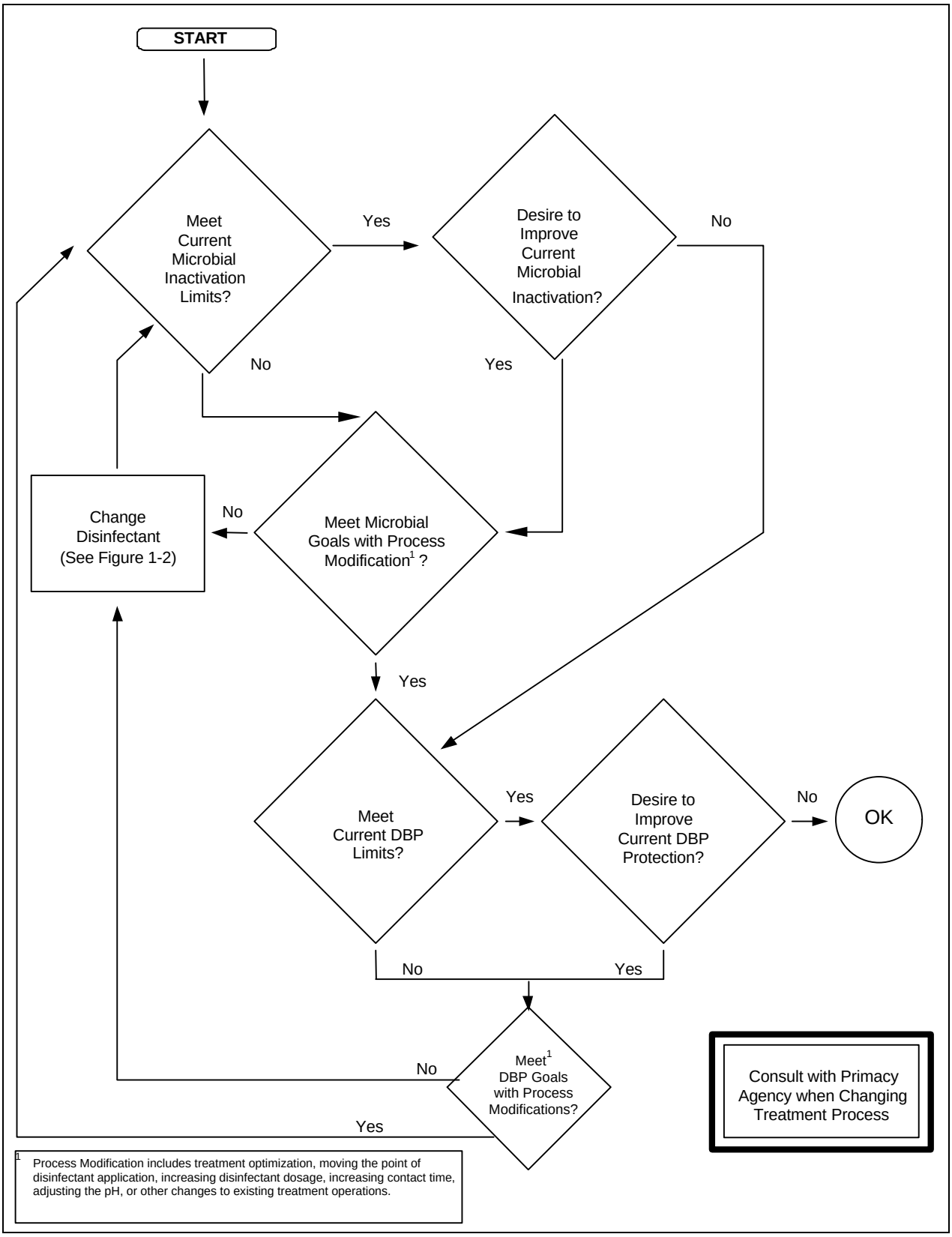

Figure 1-1. Flow Diagram to Evaluate Current Disinfection Practices

- **Bromide ion concentration.** The reactions of strong oxidants (ozone and peroxone) with bromide ion to produce hypobromous acid and bromate ion, precludes their usage with waters containing high concentrations of bromide ion. High bromide ion is defined as concentrations exceeding 0.10 mg/L.
- **Filtered versus non-filtered systems.** The use of ozone or ozone/peroxide for unfiltered systems without the benefit of biofiltration to reduce ozonation byproducts and BOM is strongly discouraged.

1.7.1.3 Select a Secondary Disinfectant

The selection of a secondary disinfectant depends on the selected primary disinfectant. Figure 1-3 identifies three decision points for secondary disinfectants:

- **Assimilable organic carbon (AOC) concentration.** AOC is produced when a strong oxidant (e.g., ozone) is used as primary disinfectant in the presence of high TOC water. High AOC is defined as concentrations exceeding 0.10 mg/L after filtration. In these cases, additional biological or GAC treatment should be considered to stabilize the finished water and prevent regrowth in the distribution system.
- **DBP formation potential (DBPFP).** The DBPFP serves as an indication of the amount of organic byproducts that could be expected to form in the distribution system if chlorine is used. Because DBP formation continues in the distribution system, the DBP content at the plant effluent should be limited. A high DBPFP is defined as a water meeting one of the following criteria:
  - TTHM seven-day formation exceeds the MCL (0.08 mg/L under Stage 1 DBPR); or
  - HAA5 seven-day formation exceeds the MCL (0.06 mg/L under the Stage 1 DBPR).
- **Distribution system retention time.** In a large distribution system, booster stations may be required to maintain the disinfection residual. Since chlorine dioxide has an upper limit for application, its usage may not be feasible if relatively high doses are required to maintain a residual in the distribution system. A distribution system retention time is considered high if it exceeds 48 hours.

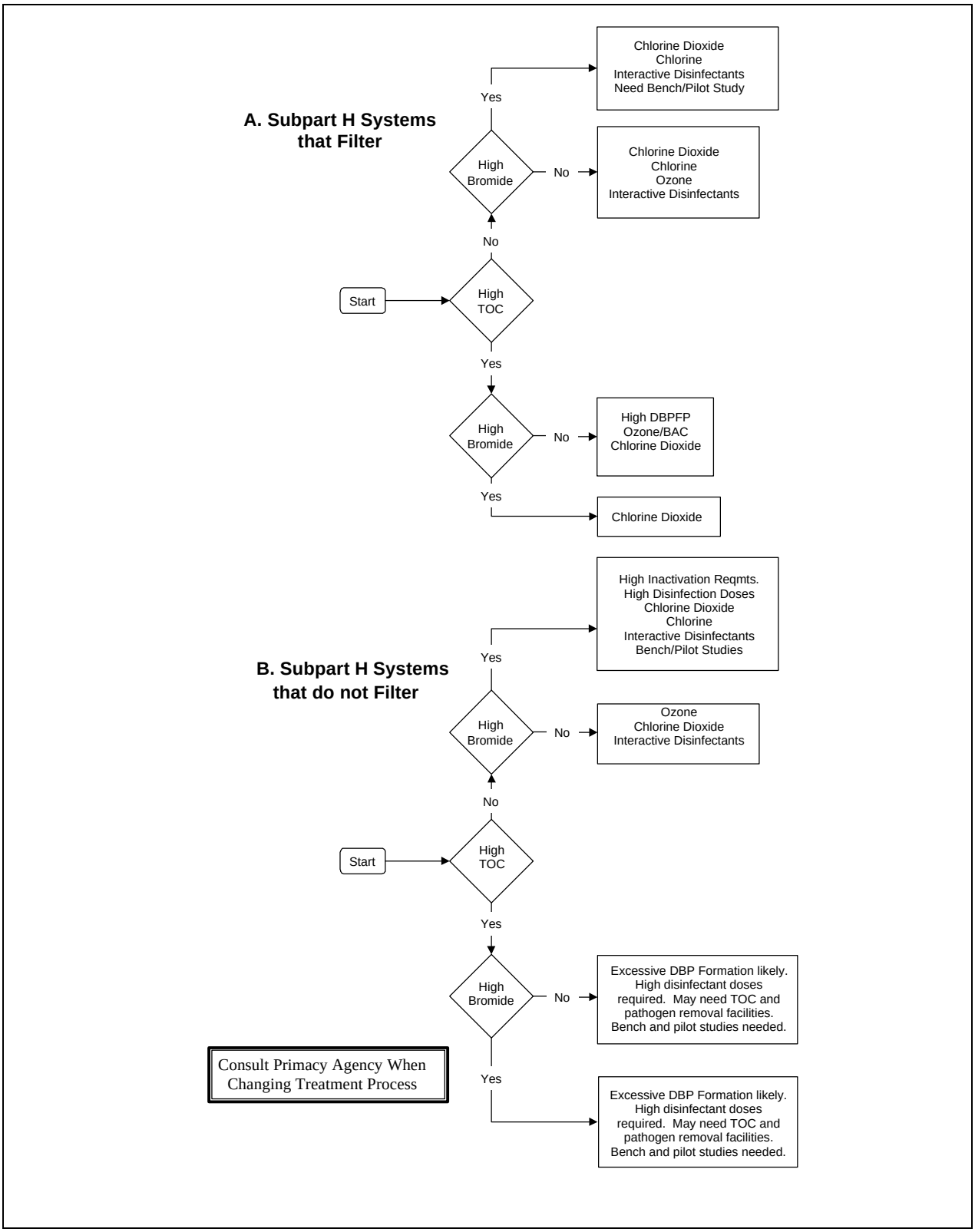

Figure 1-2. Flow Diagram to Narrow Selection of a New Primary Disinfectant

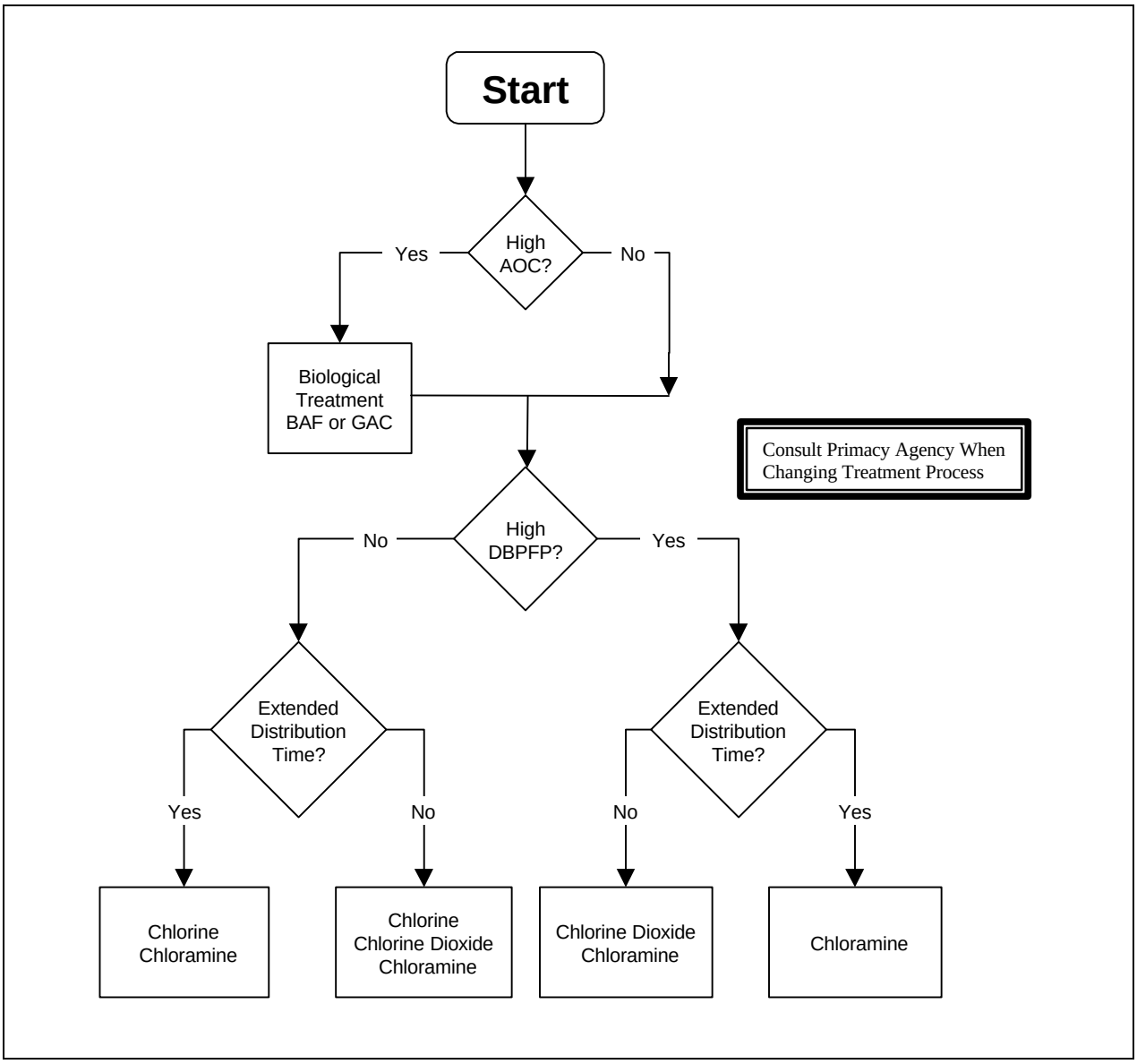

Figure 1-3. Flow Diagram to Narrow Selection of a New Secondary Disinfectant

1.7.2 Summary

The approach outlined above serves as a basis to evaluate the need for and to select the most appropriate alternative disinfectants for drinking water systems. The approach is general enough to cover the likely outcomes of the inactivation requirements and DBP formation. However, in some cases, site-specific conditions may dictate a different approach. It is important to consult with the primacy agency whenever a change in treatment is considered. Remember that the IESWTR requires certain PWSs to use disinfection profiling and benchmarking procedures when proposing changes to disinfection practices. In addition, some of the decisions may lead to a situation where additional treatment will be required. For example, filtration may be needed to reduce the disinfectant dose and

limit DBP formation in cases of high TOC and high bromide ion levels. In those instances, bench scale or pilot studies may be required to select the most appropriate disinfectant.

1.8 References

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