4. CALCULATING THE BENCHMARK

The IESWTR requires systems to use disinfection benchmarking to determine whether there may be a significant reduction in microbial inactivation as a result of modifying disinfection practices to meet the Stage 1 DBPR MCLs for TTHMs and HAA5. This determination will allow for an informed consultation with the State to assess appropriate modifications to disinfection practices, as necessary. As explained in Chapter 1, benchmarking is used to characterize the minimum level of *Giardia* and, in some cases, virus log inactivations that are provided under current disinfection practices to ensure that changes to disinfection practices do not result in inactivation levels lower than the calculated benchmark without appropriate State consultation and review. The disinfection benchmark quantifies a lower bound of the existing disinfection practices so that alternative disinfection strategies can be compared to current minimum levels of disinfection. This chapter describes the procedure to calculate a disinfection benchmark.

4.1 Applicability

Water systems required to develop a disinfection profile are required to develop a benchmark based on *Giardia* inactivation if they are planning to “significantly modify” their disinfection practices.

Systems that are planning to add or switch primary disinfectants to include ozone, chloramines, or chloride dioxide must also calculate a profile and benchmark based on virus inactivation in addition to *Giardia*. Virus inactivation must be determined for these systems to address the possibility of reduced protection against viruses when using an alternative disinfectant.

4.2 Benchmark Calculations

The calculation of disinfection profiling, including the estimated log inactivation of *Giardia* and viruses, is described in Chapter 3 of this guidance manual. Once the disinfection profile is calculated, the methodology for determining the benchmark is the same for viruses as it is for *Giardia*.

As described in the IESWTR, a disinfection benchmark is calculated using the following steps:

- Complete a disinfection profile that includes the calculation of log inactivation of *Giardia* and/or viruses for each day of the profile.
- Compute the average log inactivation for each calendar month of the profile by averaging the daily log inactivation values.

- For each 12-month period the profile covers (i.e., 0-12 months, 12-24 months, and 24-36 months), select the month with the lowest average log inactivation for each 12-month period. This month is the "lowest average month" for the 12-month period ($LowestAverageMonth_i$, where i designates the first, second, or third year and is known as the "critical period").
  - – If data from only one year are available, the critical period for that year becomes the benchmark.
  - – If data from multiple years are available, systems must calculate their benchmarks as the average of the lowest monthly averages for each year. Using three years of data as an example, the benchmark would be calculated as follows:

$$Benchmark = \frac{(LowestAverageMonth_1 + LowestAverageMonth_2 + LowestAverageMonth_3)}{3}$$

The following example demonstrates how a benchmark is calculated using three years of log inactivation data.

Disinfection Benchmark Example Calculation:

Step 1. Calculate the monthly average log inactivations for each month of disinfection profiling data. In this example, three years of data are available. Table 4-1 presents the daily log inactivation values of a hypothetical system for the month of January 1998.

The monthly average log inactivation is calculated by summing the daily values and dividing by the number of days in the month as follows:

$$Monthly\ Average\ Log\ Inactivation = \frac{\sum Daily\ Log\ Inactivation\ Values}{Days\ per\ Month}$$

For this example, the monthly average log inactivation for January 1998 is 3.94, calculated as follows:

$$\frac{\sum Daily\ Log\ Inactivation\ Values}{Days\ per\ Month} = \frac{120.10}{31} = 3.94$$

Monthly average log inactivations are then calculated in a similar manner for the other 35 months in the three-year period.

Table 4-1. Daily Log Inactivation for Hypothetical Plant for January 1998

Date	Log Inactivation	Date	Log Inactivation
1/1/98	3.26	1/17/98	3.62
1/2/98	3.17	1/18/98	4.31
1/3/98	3.36	1/19/98	4.73
1/4/98	4.82	1/20/98	4.19
1/5/98	3.65	1/21/98	3.23
1/6/98	3.22	1/22/98	4.22
1/7/98	4.03	1/23/98	3.34
1/8/98	4.97	1/24/98	3.63
1/9/98	4.77	1/25/98	4.35
1/10/98	4.31	1/26/98	3.24
1/11/98	4.57	1/27/98	3.04
1/12/98	3.89	1/28/98	3.07
1/13/98	4.11	1/29/98	3.68
1/14/98	4.30	1/30/98	4.54
1/15/98	3.10	1/31/98	4.48
1/16/98	4.89		

Step 2. Next, the minimum monthly average log inactivation values for **each year** (each 12-month period) should be identified. Table 4-2 provides the average monthly log inactivations for the hypothetical system in this example. The minimum values for each year (i.e., January 1996, January 1997, and February 1998) are highlighted.

This example is typical in that lowest monthly average log inactivation values often occur during the winter due to the reduced effectiveness of disinfection at lower temperatures. Note that the three minimum monthly values for each year are **not** the minimum three values for the entire three-year record (i.e., although the average log inactivation of 3.09 for February 1997 is less than the average log inactivation 3.23 for January 1996, the January 1996 value is used). That is, the minimum monthly average for each of the three years is used to calculate the benchmark, not the three lowest values.

Table 4-2. Monthly Average Log Inactivation Values for Hypothetical Plant

January-96	***3.23***	***January-97***	***3.04***	January-98	3.94
February-96	3.42	February-97	3.09	***February-98***	***3.07***
March-96	3.62	March-97	3.68	March-98	4.31
April-96	4.31	April-97	4.54	April-98	4.27
May-96	4.73	May-97	4.48	May-98	3.45
June-96	4.19	June-97	3.26	June-98	4.11
July-96	4.56	July-97	3.17	July-98	4.30
August-96	4.22	August-97	3.36	August-98	3.62
September-96	3.34	September-97	4.82	September-98	4.77
October-96	3.63	October-97	3.65	October-98	3.68
November-96	4.35	November-97	3.22	November-98	4.54
December-96	3.65	December-97	4.03	December-98	3.52

Step 3. Finally, the benchmark is calculated as an average of the minimum monthly average values for each of the three years. For this example, the benchmark is calculated as follows:

$$\frac{\sum LowestAverageMonths_{i}}{Number\ of\ years} = \frac{(3.23+3.04+3.07)}{3} = 3.11$$

If the plant has only two years of log inactivation data (i.e., 1997 and 1998), the average of the minimum values for 1997 and 1998 are used and the benchmark is equal to 3.06 (i.e., [3.04+3.07]/2). Likewise, if the plant has only one year of acceptable data (i.e., 1998), the single lowest average month is used and the benchmark is 3.07.

Several detailed examples are provided in Chapter 5 to further illustrate the calculation of benchmarks when modifications to disinfection practices are being considered.

4.3 The Completed Benchmark

As required in the IESWTR, water systems must work with their states when calculating benchmarks. Once the benchmarking calculations are completed, water systems must submit the calculations and supporting data to the State for consultation prior to changing disinfection practices. The State will use the benchmark to evaluate the microbial inactivation the system has achieved over time and compare this with the modified disinfection system. The use of the benchmark is discussed further in Chapter 5.

5. Using the Benchmark

The IESWTR establishes the disinfection benchmark as the lower bound on disinfection effectiveness of an existing water system. The benchmark may be used by the State as a minimum level of inactivation of *Giardia* and viruses that must be maintained by water systems when modifying their disinfection practices. The State would then require that all proposed modifications to existing disinfection practices be designed to meet current disinfection benchmarks. The State may also use the profile and benchmark to determine an appropriate alternative benchmark (see Chapter 6). Disinfection benchmarks provide a reference point for States to evaluate whether systems will compromise microbial protection when complying with the Stage 1 DBPR provisions to control disinfection byproducts.

This chapter provides a definition of significant modifications to disinfection practices, and describes State involvement in the process. Chapter 6 includes a discussion on how a State may set alternative disinfection benchmarks for systems that cannot maintain their current *Giardia* or virus benchmark.

5.1 Definition: Modifying Disinfection Practices

This section describes example modifications to disinfection practice that may trigger the benchmarking process required under the IESWTR. Although this section summarizes several DBP control alternatives as illustrative examples, it is not meant to provide a comprehensive discussion of this subject. A more complete discussion of certain DBP control alternatives is provided in the *Alternative Disinfectants and Oxidants Guidance Manual* (USEPA, 1999a).

A public water system may consider modifying their disinfection practices to comply with provisions of the Stage 1 DBPR. Significant modifications to disinfection practices trigger disinfection benchmarking requirements under the IESWTR. As described in the IESWTR, significant modifications to disinfection practices are defined as the following:

- Moving the point of disinfectant application
- Changing the disinfectant(s) used in the treatment plant
- Changing disinfection practices
- Any other modification identified by the State as significant.

A brief description of each of these four types of modifications is presented below.

5.1.1 Moving the Point of Disinfectant Application

Water systems using pre-disinfection might consider moving the point of disinfectant application further into the plant treatment train to reduce the contact time between DBP precursors and the disinfectant(s). The TTHM formation potential may be reduced by as much as 50 percent through conventional coagulation and settling (Singer and Chang, 1989; Summers et al., 1997).

Conventional water treatment plants that apply chlorine to raw water generally have adequate contact time for disinfection. Many water systems have eliminated or changed their pre-disinfection practices to control DBPs. Pre-disinfection practices involve using chemical or physical processes to remove precursors from the source water. Moving the point of disinfection after clarification with enhanced coagulation allows for greater removal of DBP precursors before disinfectant is added and also reduces the disinfectant demand of the water. When moving the point of disinfection further into the treatment process, a system must consider whether adequate contact time is available to achieve sufficient disinfection and how this modification will affect the benchmark. Systems may find that seasonal use of this modification is helpful in reducing summer DBP levels, which are typically the highest.

5.1.2 Changing the Disinfectant(s) Used In the Treatment Plant

Water systems may consider changing the disinfectant used in their treatment plant to comply with the Stage 1 DBPR MCLs. Several studies have evaluated the implications of changing the disinfection practices in water treatment plants. EPA and the Association of Metropolitan Water Agencies (AMWA) funded a two-year study of 35 water treatment facilities to evaluate DBP production. Among four of the facilities, alternative disinfection strategies were investigated to evaluate the difference in DBP production from the plants' previous disinfection strategies (or base disinfection conditions). The results were analyzed in three reports (Metropolitan and Montgomery, 1989; Jacangelo et al., 1989; Malcolm Pirnie, Inc., 1992) that documented different aspects of the study. Table 5-1 presents the 10 potential strategies often considered for primary and secondary disinfection. Table 5-2 lists the changes in DBP production observed in the four plants after eight of these new strategies were implemented.

As shown in Table 5-2, employing different and more carefully selected primary and secondary disinfectants reduced the amount of DBPs produced. In general, the results followed the characteristics of the DBPs associated with the primary disinfectant used (i.e., halogenated DBPs with chlorine compounds). Organic oxidation products form when strong oxidants such as ozone are used. However, by carefully selecting the primary and secondary disinfectants, and avoiding long contact times and high dosages of halogens, the total DBP formation declined. It is important to note that the study did not evaluate bromate formation.

Table 5-1. Strategies for Primary and Secondary Disinfectants

Base Disinfection Condition	Modified Disinfection Practice
Chlorine/Chlorine	Chlorine/Chloramine
Chlorine/Chlorine	Chloramine/Chloramine
Chlorine/Chlorine	Chlorine dioxide/Chloramine
Chlorine/Chlorine	Ozone/Chlorine
Chlorine/Chlorine	Ozone/Chloramine
Chlorine/Chlorine	Chlorine dioxide/Chlorine
Chlorine/Chloramine	Ozone/Chloramine
Chlorine/Chloramine	Chlorine dioxide/Chloramine
Ozone/Chlorine	Ozone/Chloramine
Chloramine/Chloramine	Ozone/Chloramine

Note: Disinfectants are listed as primary disinfectant/secondary disinfectant

Since systems can initially determine what is considered a significant change in disinfection practice (including those specifically identified by the State), they may also consider changing the disinfectant and point of disinfectant application. For example, a system shifting from chlorine/chlorine to chlorine dioxide/chloramine may want to consider shifting the ammonia application point after the point of chlorine application to allow for some chlorine contact time for virus inactivation.

5.1.3 Changes to Disinfection Practices

Other significant changes to disinfection practices also require water systems to consult with the State before making the treatment change. Types of modifications considered significant include, but are not limited to, the following:

- Changes in the contact basin geometry and baffling conditions
- Increases in the pH during disinfection by greater than 1 unit (for chlorine only)
- Changes in the raw water source.

The IESWTR requires that water systems provide information to the State supporting the rationale for the potential treatment change. Types of supporting materials include a description of the proposed change, the disinfection profile, and an analysis of how the proposed change will affect the current disinfection benchmark.

Table 5-2. Impacts of Disinfection Practice on DBP Formation

Disinfection Byproduct	Change in Disinfection Practice (Primary Disinfectant/Secondary Disinfectant)				
	Chlorine/Chlorine To Chlorine/Chloramines	Chlorine/Chlorine To Ozone/Chlorine		Chlorine/Chloramines to Ozone/Chloramines	Chlorine/Chlorine to Chloramines/Chloramines
	Utility #7	Utility #19	Utility #36	Utility #7	Utility #36
Total Trihalomethanes	Decrease	Decrease	No change	Decrease	Decrease
Total Haloacetic Acids	Decrease	Decrease	No change	Decrease	Decrease
Total Haloacetonitriles	Decrease	Decrease	No change	Decrease	Decrease
Total Haloketones	Decrease	No change	Increase	Increase	Decrease
Total Aldehydes	Not analyzed	Not analyzed	Increase	Not analyzed	Decrease
Chloropicrin	No change	Increase	Increase	Decrease	No change
Chloral Hydrate	Decrease	Increase	Increase	Decrease	Decrease
Cyanogen Chloride	No change	Not analyzed	No change	No change	Increase

Disinfection Byproduct	Change in Disinfection Practice (Primary Disinfectant/Secondary Disinfectant)				
	Ozone/Chlorine To Ozone/Chloramines	Chloramines/Chloramines To Ozone/Chloramines		Chlorine/Chlorine To Ozone/Chloramines	
	Utility #36	Utility #25	Utility #36	Utility #7	Utility #36
Total Trihalomethanes	Decrease	Decrease	No change	Decrease	Decrease
Total Haloacetic Acids	Decrease	Decrease	No change	Decrease	Decrease
Total Haloacetonitriles	Decrease	No change	No change	Decrease	Decrease
Total Haloketones	Decrease	No change	Increase	Decrease	Decrease
Total Aldehydes	Decrease	Increase	Increase	Not analyzed	Increase
Chloropicrin	Increase	Increase	Increase	Decrease	Increase
Chloral Hydrate	Decrease	Decrease	Increase	Decrease	Decrease
Cyanogen Chloride	Increase	Increase	Increase	No change	Increase

Notes: Results based on full-scale evaluation at Utilities #19 and #25 and on pilot scale evaluations at Utilities #7 and #36.
Free chlorine contact time was 4 hours for Utility #7 during use of chlorine/chloramine strategy.

Systems must demonstrate efficacy of chloramines as a primary disinfectant if they are to be used as such. Source: Malcolm Pirnie, Inc., 1992; Jacangelo et al., 1989.

Source: Malcolm Pirnie, Inc., 1992; Jacangelo et al., 1989.

5.1.4 Other Modifications Identified by the State

The State may ultimately determine what changes in water system operations constitute a change in disinfection practices. If the State concludes that a change in disinfection practice is a significant modification, the water system must develop and submit a disinfection benchmark.

The modifications listed in Sections 5.1.1 through 5.1.3 are not an exhaustive list and may be amended at the State's discretion. Therefore, a water system should check with the State program office for assistance in determining whether the proposed change triggers the disinfection benchmarking procedure. Water systems can refer to *Alternative Disinfectants and Oxidants Guidance Manual* for additional information and references on disinfectant capabilities and the potential implications of modifying disinfection practices (USEPA, 1999a).

5.2 Communicating with the State

The IESWTR requires public water systems to consult with the State in order to assess the impact that disinfection modifications may have on their current log inactivation levels. Using the disinfection benchmarking method, the State may determine if the change in disinfection practice is acceptable (e.g., meets the current disinfection benchmark). However, there is no federal requirement for State approval of disinfection modifications.

As required under the IESWTR, the system must submit profiling information to the State. Profiling information includes:

- Detailed plans (schematic) and operating strategy of the proposed modifications to disinfection practices.
- The disinfection profile and supporting calculations and data for both the existing practice and the proposed change.
- The current disinfection benchmark value and supporting calculations.
- Detailed calculations that assess the potential impact of the intended changes in disinfection practice (i.e., with regard to anticipating changes in log inactivation to achieve modifications on current log inactivation (discussed in Section 5.3)).

Note that systems adding or switching to ozone or chloramines must provide the above information for both *Giardia* and viruses. EPA strongly recommends that systems also calculate a virus profile and benchmark if they are switching to chlorine dioxide.

5.3 Calculations to Identify Modification Impact

To assess the impact of modifications on current log inactivation, systems need to perform several additional benchmarking calculations. Specifically, water systems should calculate "modification benchmarks," based on the current operating conditions before the process change is made. These modification benchmarks should be compared to the original benchmark to evaluate the expected inactivation level of the modified disinfection practice.

The steps to calculate these modification benchmarks are as follows:

- Identify the lowest average months from the original profile (i.e., the one to three months that were averaged to calculate the original benchmark).
- Using the temperature, pH, and contact times (unless the modification significantly changes these values) from the original profile calculations, systems calculate the daily log inactivation for *Giardia* (and/or viruses) for each day of the month under the proposed modification (i.e., for conditions after the modification is complete). The water system will need to assume reasonable values for the disinfectant residuals. It may also need to calculate or estimate contact times, or identify new points of disinfectant residual sampling to reflect the modification.
- Calculate the average log *Giardia* and/or virus inactivation for the months identified in the first bullet.
- Calculate the average of the monthly values. This value is the modification benchmark.
- Compare the original benchmark to the modification benchmark. If the modification benchmark is greater than the original benchmark, the modification will likely be acceptable after consultation with the State. Modification benchmarks lower than the original benchmark should be evaluated by the State to determine whether the resulting level of disinfection is still considered adequate based on source water quality and watershed conditions (discussed further in Chapter 6).

The system and State should discuss the reasons for any modification and whether better options exist, and assess the modification's impact on log inactivation. The State and the system should jointly assess the impact that the proposed modification will have on log inactivation levels of *Giardia* and/or viruses.

A detailed example of calculating the impact of changes in disinfection practices, including the comparison of original and modification benchmarks, is provided in Section 5.5.

5.4 Alternative Benchmark

As addressed in the IESWTR, situations will exist when a system may need to develop an alternative benchmark to comply with the Stage 1 DBPR provisions. These situations are detailed in Chapter 6.

The disinfection benchmark can also be met by a combination of inactivation with a chemical disinfectant and an improvement in the physical removal of pathogens after consultation with the State. Consider an unfiltered system with a disinfection benchmark of 4-logs for *Giardia*. If this system were to implement conventional filtration and receive 2.5-log *Giardia* removal credit, the chemical disinfection required to meet the existing disinfection benchmark could be reduced to 1.5-log *Giardia* inactivation. Likewise, a utility that makes a process enhancement to improve pathogen removal could receive credit toward achieving its existing disinfection benchmark. Consider a conventional filtration plant that upgrades its process to include ultrafiltration using membranes. Because ultrafiltration has been demonstrated to achieve greater than 6-logs of *Giardia* removal, the existing *Giardia* disinfection benchmark could be reduced by an amount deemed acceptable by the State (AWWARF, 1997). The remainder of the existing disinfection benchmark could be accomplished with chemical disinfection.

5.5 Illustrative Examples

This section considers simple examples of disinfection byproduct control. These examples are applicable to conventional filtration plants that are considering additional control of DBPs to comply with the Stage 1 DBPR. The examples include process changes that may accomplish the goals of controlling DBP levels and disinfection benchmarking. This section does not discuss major process changes, such as alternative primary disinfectants, since they require extensive engineering evaluation. As discussed previously, the system should only implement significant changes to a disinfection practice after careful consideration and consultation with the State. In most circumstances, the system should seek the assistance of a qualified professional engineer to develop and implement a process change. The *Microbial and Disinfection Byproducts Simultaneous Compliance Guidance Manual* (USEPA, 1999b) presents case studies and scenarios involving solutions to some of the potential conflicting compliance issues.

5.5.1 DBP Control using Enhanced Coagulation

5.5.1.1 Base Conditions (Plant A)

This section considers the base condition to be a conventional filtration plant (Plant A) that practices prechlorination. Table 5-3 lists the important raw water characteristics, while Table 5-4 describes the important unit processes of Plant A.

Table 5-3. Raw Water Quality (Plant A)

Parameter	Value
PH	7.5-8.0
TOC (mg/L)	3.8-5.0
UV-254 (1/cm)	0.1-0.15
Bromide (mg/L)	0.15-0.2
Temperature (°C)	6-20
Alkalinity (mg/L as $CaCO_3$)	50-60
SUVA (L/mg-m)	~ 2.5 – 3.7

Table 5-4. Base Condition Unit Processes (Plant A)

Process	Characteristics
Influent	Raw Water Characteristics above
Chlorine	Dose 4 mg/L
Alum	Dose 20 mg/L
Rapid Mix	5 minutes detention, 0.1 baffling factor
Flocculation	20 minutes detention, 0.3 baffling factor
Settling	90 minutes detention, 0.3 baffling factor
Filtration	15 minutes detention, 0.5 baffling factor
Clearwell	60 minutes detention, 0.1 baffling factor
Distribution	3 days maximum detention time

The disinfection benchmark for *Giardia* for this conventional filtration plant is 0.75-logs. This system applies chlorine to the raw water for disinfection to achieve at least a 0.2 mg/L distribution system residual. Since chlorine and alum are both acids, the pH is reduced from about 7.5 in the influent to 7.1 in the finished water. Total organic carbon is removed in the coagulation/settling process from 5.0 mg/L in the raw water to 3.7 mg/L in the finished water (which is inadequate to meet Stage 1 DBPR requirements for enhanced coagulation). This results in a concurrent decline in SUVA.

The TTHM and HAA5 concentrations experienced by this system with its three-day detention time in the distribution system are listed in Table 5-5. The running annual average (RAA) TTHM and HAA5 values are 87 and 58 µg/L, respectively. Because the TTHM value exceeds the Stage 1 MCL, this system must implement a strategy for TTHM control. Also, since the HAA5 concentration is close to the MCL, the system should implement a HAA5 control strategy.

Table 5-5. System DBP Concentrations (Plant A)

Parameter	Summer	Winter	RAA
TTHM (µg/L)	145	29	87
HAA5 (µg/L)	71	44	58

Note: Running annual average is based on quarterly sampling (not shown).

The plant examines making four modifications to its disinfection practices to control DBPs. These modifications include:

1. Practicing enhanced coagulation as required by the Stage 1 DBPR
2. Installing chloramination to provide residual disinfection
3. Moving the point of chlorine application after settling (possibly a seasonal change)
4. Improving hydraulic characteristics of clearwell.

The system operator assesses whether practicing enhanced coagulation is likely to achieve the desired TTHM and HAA5 reductions. Based on UV absorbance, TOC concentrations, and DBP levels, the plant's management decides to employ enhanced coagulation as a first step to control DBP levels.

5.5.1.2 Enhanced Coagulation for DBP Control (Plant A)

Enhanced coagulation improves the removal of organic carbon in the coagulation and settling processes. Because the system is not exempt from enhanced coagulation requirements, it must achieve TOC removal requirements as stated in Table 5-6. Because waters with greater alkalinity and lower TOC concentrations are more difficult to coagulate, performance requirements in these categories are lower than for other categories.

Table 5-6. Proposed Required Removal of TOC by Enhanced Coagulation/Enhanced Softening for Surface Water Systems Using Conventional Treatment

Source Water TOC (mg/L)	Source Water Alkalinity (mg/L as $CaCO_3$)		
	0-60	>60-120	>120[1]
>2.0-4.0	35.0%	25.0%	15.0%
>4.0-8.0	45.0%	35.0%	25.0%
>8.0	50.0%	40.0%	30.0%

Enhanced coagulation alternative compliance criteria applicable to waters with raw-water SUVA ≤ 2.0 L/mg-m.

[1] Systems practicing precipitative softening must meet the TOC removal requirements in this column.

The system in question has a raw water alkalinity of 50-60 mg/L as $CaCO_3$ and a raw water TOC of 4.5-5.0 mg/L. Based on Table 5-6, these conditions require the utility to remove 45 percent or more TOC through the coagulation and settling process as an annual average (refer to the *Guidance Manual for Enhanced Coagulation and Enhanced Precipitative Softening* for additional information (USEPA, 1999g)). The utility currently adds 20 mg/L of alum. This alum dose reduces the TOC from 5.0 to 3.7 mg/L through settling. This is equivalent to 26 percent removal ([5.0-3.7]/5.0*100%). Through jar testing, the plant operators determine that it needs to add 40 mg/L alum to achieve 45 percent removal of TOC (i.e.; to achieve 2.7 mg/L TOC in its settled water). Practicing enhanced coagulation in settled water is expected to result in the following DBP concentrations in the distribution system (Table 5-7).

Table 5-7. System DBP Concentrations with Enhanced Coagulation, Settled Water Chlorination (Plant A)

Parameter	**Summer**		**Winter**		**RAA**	
	Before EC	After EC	Before EC	After EC	Before EC	After EC
TTHM (µg/L)	145	99	29	20	87	60
HAA5 (µg/L)	71	54	44	33	58	44

Note: Running Annual Average (RAA) is based on quarterly sampling (not shown).
EC = Enhanced Coagulation

In addition to controlling DBPs, enhanced coagulation allows for more effective disinfection. This occurs by two mechanisms:

- A greater residual is provided for the same chlorine dose since the chlorine demand is lower in water treated by enhanced coagulation.
- Chlorine is more effective at inactivating *Giardia* at the lower pH resulting from enhanced coagulation.

The disinfectant residual achieved by a given dose is a function of contact time and disinfectant demand of the water, among other factors. Because TOC exerts a disinfectant demand, the disinfectant residual will be greater when practicing enhanced coagulation (for the same chlorine dose).

The addition of alum to water decreases the pH of the water. For instance, the pH of the settled water under the original 20 mg/L alum dose was 7.1, whereas the pH of the settled water under the 40 mg/L alum dose is 6.6. This drop in pH with enhanced coagulation may adversely impact corrosion in the distribution system and should be mitigated appropriately. The drop in pH actually improves disinfection, because chlorine is more effective at inactivating *Giardia* at lower pH. Acids, such as hydrochloric acid, are used in treatment plants to lower pH levels to enhance coagulation and improve filter performance. Table 5-8 indicates the improved disinfection occurring due to enhanced coagulation and disinfection of settled water. The system also maintains a disinfection level above its current benchmark. The system also may reduce its chlorine dose to maintain its pre-enhanced coagulation chlorine residual levels of 0.8mg/L and to conserve financial reserves.

Table 5-8. Impact of Enhanced Coagulation on Disinfection (Plant A)

Coagulation Practice	Chlorine Residual in Finished Water (mg/L)	Contact Time (minutes)	CT (mg-min/L)	pH at Residual Sampling Point	Log Inactivation of *Giardia* at 5°C
Existing (20 mg/L Alum)	0.8	47	37.6	7.1	0.75
Enhanced (40 mg/L Alum)	1.2	47	56.6	6.6	1.3

5.5.2 Treatment Changes for DBP Control When Enhanced Coagulation is Insufficient

5.5.2.1 Base Conditions (Plant B)

The base condition considered for this example, Plant B, is a conventional filtration plant that practices prechlorination. Table 5-9 lists the important raw water characteristics for this plant, while Table 5-10 describes the important unit processes of Plant B.

Table 5-9. Raw Water Quality (Plant B)

Parameter	Value
pH	7.6-7.9
TOC (mg/L)	4.0-5.0
UV-254 (1/cm)	0.15-0.2
Bromide (mg/L)	0.15-0.2
Temperature (°C)	5.0-24
Alkalinity (mg/L as CaCO3)	50-60

Table 5-10. Base Condition Unit Processes (Plant B)

Process	Characteristics
Influent	Raw Water Characteristics above
Chlorine	Dose 4 mg/L
Alum	Dose 20 mg/L
Rapid Mix	5 minutes detention, 0.1 baffling factor
Flocculation	20 minutes detention, 0.3 baffling factor
Settling	80 minutes detention, 0.3 baffling factor
Filtration	15 minutes detention, 0.5 baffling factor
Clearwell	60 minutes detention, 0.1 baffling factor
Distribution	3 days maximum detention time

The disinfection benchmark for *Giardia* for this conventional filtration plant is 1.0 log. This system applies chlorine to the raw water for disinfection and maintains a detectable residual throughout the distribution system. The effects of both chlorine and alum on pH is evident in the decrease in pH levels from about 7.6 in the influent to 6.9 in the finished water. TOC is removed in the coagulation/settling process from 5.0 mg/L in the raw water to 3.7 mg/L in the finished water. This results in a concurrent decline in UV absorbance.

The TTHM and HAA5 concentrations experienced by this system with its 3-day detention time in the distribution system are listed in Table 5-11. The running annual average (RAA) TTHM and HAA5 values are 99 and 65 μg/L. Because the TTHM value exceeds the Stage 1 MCL, this system must implement a strategy for DBP control.

Table 5-11. System DBP Concentrations (Plant B)

Parameter	Summer	Winter	RAA
TTHM (μg/L)	165	39	99
HAA5 (μg/L)	85	55	65

Note: Running annual average is based on quarterly sampling (not shown).

The plant examines making four modifications to its disinfection practices to control DBPs. These modifications include:

1. Practicing enhanced coagulation as required by the Stage 1 DBPR
2. Installing chloramination to provide residual disinfection
3. Moving the point of chlorine application after settling (possibly a seasonal change)
4. Improving hydraulic characteristics of the clearwell.

5.5.2.2 Enhanced Coagulation for DBP Control (Plant B)

Because the system is not exempt from enhanced coagulation requirements, it must achieve the TOC removal requirements stated in Table 5-6.

The system in question has a raw water alkalinity of 50-60 mg/L as $CaCO_3$ and a raw water TOC of 4.5-5.0 mg/L. Based on Table 5-6, these conditions require the utility to remove 45 percent or more TOC through the coagulation and settling process as an annual average. The utility currently adds 20 mg/L of alum. This alum dose reduces the TOC from 5.0 to 3.7 mg/L through settling. This is equivalent to 26 percent removal ([5.0-3.7]/5.0*100%). Through jar testing, the plant operators determine that they need to add 40 mg/L alum to achieve 45 percent removal of TOC (i.e., to achieve 2.7 mg/L TOC in its settled water). Practicing enhanced coagulation results in the following DBP concentrations in the distribution system (Table 5-12).

Table 5-12. System DBP Concentrations with Enhanced Coagulation (Plant B)

Parameter	**Summer**		**Winter**		**RAA**	
	Before EC	After EC	Before EC	After EC	Before EC	After EC
TTHM (μg/L)	165	99	39	25	99	73
HAA5 (μg/L)	85	65	55	38	65	57

Note: Running annual average is based on quarterly sampling (not shown).

In addition to reducing DBPs, enhanced coagulation allows for more effective disinfection and some TOC removal. Because TOC exerts a disinfectant demand, the disinfectant residual will be greater (for the same chlorine dose).

The addition of alum to water decreases the pH of the water. For instance, when the pH of the settled water under the original 20 mg/L alum dose was 7.1, the pH of the settled water under the 40 mg/L dose was 6.5. This drop in pH with enhanced coagulation may adversely impact corrosion in the distribution system and should be mitigated appropriately. The drop in pH actually improves disinfection, however, since chlorine is more effective at inactivating *Giardia* at lower pH. Table 5-13 indicates the improved coagulation occurring due to enhanced coagulation. The system also maintains a disinfection level above its current benchmark.

Table 5-13. Impact of Enhanced Coagulation on Disinfection (Plant B)

Coagulation Practice	Chlorine Residual in Finished Water (mg/L)	Contact Time (minutes)	CT (mg-min/L)	pH at Residual Sampling Point	Log Inactivation of Giardia at 5°C
Existing (10 mg/L Alum)	1.4	44	61.6	7.1	1
Enhanced (40 mg/L Alum)	1.8	44	79.2	6.5	1.7

While improving its level of *Giardia* inactivation, the system fails to reach the desired reductions in TTHM and HAA5 levels (see Section 2.5). The system considers switching to chloramines for a secondary disinfectant in order to reduce DBP levels.

5.5.2.3 Chloramines

Chloramines can be used as a secondary disinfectant to control DBP formation in the distribution system. This system is considering the application of free chlorine to its raw water, with application of ammonia to the suction line of the high service pumps. This allows disinfection using free chlorine, while quenching the free chlorine residual with ammonia to limit formation of regulated DBPs in the distribution system. The use of chloramines for residual disinfection is dicussed extensively in the *Alternative Disinfectants and Oxidants Guidance Manual* (USEPA, 1999a).

The use of chloramines by this system will not affect its primary disinfection because ammonia is applied following the clearwell. Therefore, the disinfection level listed in Table 5-13 for enhanced coagulation (1.7-log *Giardia* inactivation) is still applicable for this system using chloramines for residual disinfection.

Chloramines will effectively control DBP formation in the distribution system. For systems that exceed DBP MCLs within the plant, rather than the distribution system, ammonia would need to be applied prior to the clearwell for effective DBP control. For this system, application of ammonia at the suction line of the high service pumps (after clearwell) allows disinfection levels to be maintained while further controlling DBPs. For this system, use of chloramines combined with enhanced coagulation and settled water chlorination results in TTHM and HAA5 concentrations of 66 μg/L and 51 μg/L running annual average, respectively.

5.5.2.4 Moving the Point of Chlorine Application after Settling

The purpose of this modification is to reduce the concentration of DBP precursors prior to the addition of chlorine. TOC is removed during the coagulation/settling process. For this system, the TOC level declines from about 5.0 to 3.7 mg/L after settling, with the addition of 20 mg/L of alum. Moving the point of chlorination, therefore, results in the chlorination of water with significantly lower TOC. Because TOC is a surrogate measure for natural organic material (a principal DBP precursor), and the TOC level has been reduced, this should reduce the formation of DBPs.

Moving the point of chlorine application from raw water to settled water results in DBP formation shown in Table 5-14. The chlorine dose is not changed from the baseline condition which is 4.0 mg/L. This modification results in a decrease in TTHM concentration of about 20 percent and HAA5 concentration of about 30 percent.

Table 5-14. System DBP Concentrations After Enhanced Coagulation and Moving the Point of Chlorination

Parameter	**Summer**		**Winter**		**RAA**	
	Only EC	After moving POC	Only EC	After moving POC	Only EC	After moving POC
TTHM (μg/L)	99	80	25	20	73	55
HAA5 (μg/L)	65	46	38	27	57	35

Note: Running annual average is based on quarterly sampling (not shown).
POC = Point of Chlorination
EC = Enhanced Coagulation

Under baseline conditions, the system added chlorine to the raw water and used the detention time available in the rapid mix, flocculation, and sedimentation basins. This contact time is about 31 minutes at peak hourly flow (i.e., 70 percent of total contact time available). Once the system moves chlorine application to settled water, it loses the benefit of this contact time.

The achieved chlorine residual is a function of chlorine dose and decay. Chlorine decay depends on the chlorine demand of the water and contact time, among other factors. Organic carbon exerts chlorine demand. Because settled water contains less TOC and because chlorine is in contact with water for a shorter duration, the chlorine residual in the finished water is greater when chlorine is applied to settled water (Table 5-15). For application of chlorine to settled water, the chlorine residual is greater but the contact time is shorter. This results in an overall decrease in disinfection level (i.e., the CT) by about 50 percent.

Table 5-15. Impact of Moving Chlorine Application Point on Disinfection

Chorine Application Point	**Contact Time (minutes)**	**Chlorine Residual in Finished Water (mg/L)**	**CT (mg-min/L)**	**Log Inactivation of Giardia at 5°C and pH 6.5**
Raw Water	44	1.8	79.2	1.7
Settled Water	13.5	2.8	37.8	0.8

Moving the point of chlorine application from raw to settled water does assist in controlling DBP formation but is less than the disinfection benchmark. However, if the chlorine application point is moved seasonally, this may not be an issue. This is discussed further in the next section.

5.5.2.5 Seasonal Chlorine Application Points

The plant operators consider changing the point of disinfectant application only during summer when DBP formation is highest, and the CTs required for pathogen inactivation are at their lowest. A seasonal change in the point of chlorine application can assist in controlling DBPs and meeting disinfection benchmarking goals.

The disinfection benchmark characterizes the minimum disinfection achieved based on historic plant operating data. Because the effectiveness of disinfection is significantly reduced at lower temperatures, the benchmark is typically determined during the winter months (i.e., December, January, and February). Therefore, the existing disinfection level in these months should be maintained. However, disinfection is more effective in summer, and therefore does not require as high a CT as in winter. This may allow a utility to move the point of chlorine application downstream in the treatment train when less contact time is needed.

Disinfection byproduct formation is typically greatest in summer, since the rate of DBP formation is greater at higher temperatures and in the presence of DBP precursors (e.g., when algae may be at their highest concentrations.) These contrasting issues of needing to maintain disinfection levels in winter and needing to control DBPs primarily during summer lead to the concept of seasonal DBP application points. That is, apply chlorine early in the process train in winter to maximize contact time and apply chlorine later in the process train in summer to control DBPs.

The plant operators decide to use the existing raw water chlorination point from December through February, and move the point of chlorination to settled water from March through November. The winter chlorination point and dose will be the same as historic practices, so the existing benchmark will be maintained. The impact of seasonal chlorine application points on DBP concentrations is summarized in Table 5-16. The seasonal chlorine application points evaluated at this utility satisfy the existing disinfection benchmark (1.0) by maintaining critical winter disinfection.

Table 5-16. System DBP Concentrations After Enhanced Coagulation and Moving of Chlorine Application Points

Parameter	Summer	Winter	RAA
TTHM (µg/L)	80	25	57
HAA5 (µg/L)	46	38	42

Note: Running annual average is based on quarterly sampling (not shown).
RAA = Running Annual Average

Table 5-17 shows the impact of moving the disinfection point during the summer season on *Giardia* inactivation. By moving the point of chlorine application to settled water during warmer periods, the DBP concentrations were controlled below the Stage 1 MCLs. This was accomplished using the same chlorine dose. A utility considering this alternative must ensure that the minimum disinfection requirements of the SWTR are met at all times and that an adequate disinfectant residual is provided for distribution.

Table 5-17. Impact Of Moving Chlorine Application During The Summer Season

Chorine Application Point	**Contact Time (minutes)**	**Chlorine Residual in Finished Water (mg/L)**	**CT (mg-min/L)**	**Log Inactivation of *Giardia* at 20°C and pH 6.5**	**Log Inactivation of *Giardia* at 5°C and pH 6.5**
Raw Water (Winter)	44	1.8	79.2	--	1.7
Settled Water (Summer)	13.5	2.8	37.8	2.0	--

5.5.2.6 Clearwell Baffling

Moving the point of chlorination to settled water combined with practicing enhanced coagulation will allow plants to comfortably meet Stage 1 DBP MCLs. Enhanced coagulation also improves disinfection, but it cannot make up for the reduced contact time associated with moving chlorine application from raw to settled water. Compare the Log inactivation values for raw water (1.0) with enhanced coagulation (1.7) presented on Table 5-18. For this system, moving the point of chlorination combined with enhanced coagulation results in a 50 percent decrease in disinfection level. Although seasonal chlorination point strategy could meet disinfection benchmarking goals by maintaining existing winter disinfection, another method to meet benchmarking goals would be to improve the hydraulics of the clearwell using baffles.

Baffling and disinfection contact time are discussed extensively in Appendix D. The clearwell for the system being discussed is not baffled and has been estimated to have a baffling factor (T_{10}/T) of 0.1. This is the worst classification of baffling for disinfection contact time and the system only receives credit for 10 percent of the theoretical detention time (60 minutes). Therefore, opportunity exists to substantially improve disinfection by improving the hydraulic characteristics of the clearwell for disinfection contact time.

Table 5-18. Cumulative Impact of Settled Water Chlorination, Enhanced Coagulation and Clearwell Baffling on Disinfection (Plant B)

Modification	Disinfection Contact Time (minutes)	Disinfectant Residual (mg/L)	CT (mg-min/L)	Finished Water pH	Log Inactivation of Giardia
1. Original Raw Water Chlorination at 5°C	44	1.4	61.6	7.1	1.0 (benchmark)
2. Enhanced Coagulation at 5°C	44	1.8	79.2	6.5	1.7
3. Seasonal Settled Water Chlorination at 20°C	13.5	2.8	37.8	6.5	2.0
4. Regular Settled Water Chlorination at 5°C	13.5	2.8	37.8	6.9	0.64
5. Enhanced Coagulation, Settled Water Chlorination at 5°C	13.5	2.8	37.8	6.5	0.8
6. Enhanced Coagulation, Settled Water Chlorination, Clearwell Baffling at 5°C	37.5	2.8	105	6.5	2.7

The system has developed a design to baffle the clearwell and improve its baffling factor from 0.1 to 0.5 (average conditions). The baffling design includes inlet and outlet baffles, with some intra-basin baffles. Using the theoretical detention time of 60 minutes, a baffling factor of 0.1 yields 6 minutes of contact time (T_{10}) while a factor of 0.5 yields 30 minutes of contact time. Please review other sections of this manual for calculations using baffling factors and guidance on baffling the clearwell or other basins. Table 5-18 compares the cumulative impact on disinfection of the modifications presented above: moving point of chlorination (regular or during summer season only), enhanced coagulation, and clearwell baffling.

Table 5-18 indicates that enhanced coagulation, seasonal settled water chlorination, and clearwell baffling together provide greater disinfection than the original practice of chlorinating raw water, using a chlorine dose of 4 mg/L for both situations. Baffling the clearwell is not expected to significantly impact DBP formation. Therefore, RAA TTHM and HAA5 concentrations are expected to be 57 μg/L and 46 μg/L, respectively. The greater disinfection provided through baffling modification, enhanced coagulation and settled water chlorination, would allow the utility to reduce its chlorine dose to less than 3 mg/L and still meet or exceed its disinfection benchmark, further controlling DBP concentrations.

5.5.3 Summary of Treatment Modification Strategies Impact on Disinfection and DBP Control

The system described as Plant B had running annual average DBP concentrations greater than the Stage 1 DBPR MCLs. The system considered four strategies for DBP control. These strategies and their impacts on disinfection and byproduct formation are summarized in Table 5-19. This experience demonstrates how a single change did not allow simultaneous compliance. Rather, several carefully selected components were integrated for DBP control while maintaining the historical disinfection benchmark.

Table 5-19. Summary Impacts of DBP Control Strategies Original Practice – Raw Water Chlorination

Strategy	Disinfection	Byproduct Control
Settled Water Chlorination	-	+
Enhanced Coagulation	+	+
Clearwell Baffling	+	0
Chloramines for residual disinfection	0	+

Note: + for improvement, - for degradation, 0 for no impact

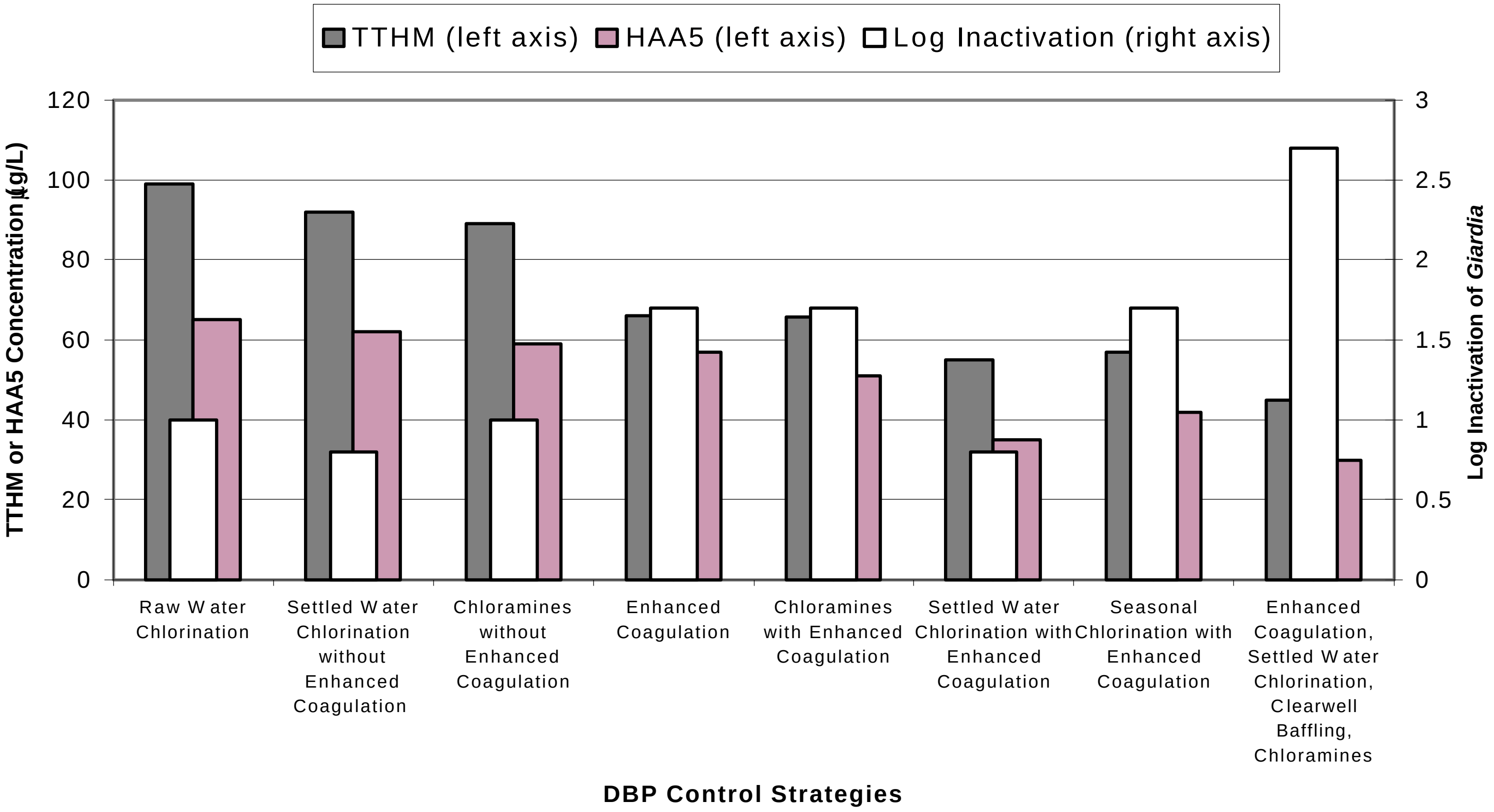
Table 5-20 and Figure 5-1 summarizes the experience of "Plant B" in selecting a DBP control strategy that maintains historical critical period disinfection levels. No single component solved these problems. Instead, several carefully selected components were required to meet DBP MCLs while maintaining historical critical period disinfection. Moving the point of chlorination to settled water combined with enhanced coagulation allowed the utility to meet Stage 1 DBP MCLs, but sacrificed disinfection due to the shorter chlorine contact time. Historical disinfection levels were achieved by also baffling the clearwell to recover some of the lost disinfection contact time. Another alternative for meeting the disinfection benchmark would be to maintain seasonal chlorine application points. This strategy would chlorinate raw water during critical period disinfection months used to calculate the benchmark (i.e.; winter conditions). During warmer conditions, chlorine would be applied to settled water to control DBPs. Seasonal chlorine application points combined with enhanced coagulation would have also met the Stage 1 DBP MCLs and disinfection benchmarking goals for the system under consideration.

Table 5-20. Impact of DBP Control Strategies on Disinfection and Byproduct Formation

Treatment Type	**TTHM Concentration[1] (µg/L)**	**HAA5 Concentration[1] (µg/L)**	**Critical Log Inactivation of *Giardia*[2]**
Raw Water Chlorination	99	65	1.0
Settled Water Chlorination without Enhanced Coagulation	92	62	0.8
Chloramines without Enhanced Coagulation	89	59	1.0
Enhanced Coagulation	73	57	1.7
Chloramines with Enhanced Coagulation	66	51	1.7
Settled Water Chlorination with Enhanced Coagulation	55	35	0.8
Seasonal Chlorination with Enhanced Coagulation	57	42	1.7
Enhanced Coagulation, Settled Water Chlorination, Clearwell Baffling, Chloramines	45	30	2.7

[1] as running annual average

[2] at 5°C and pH 6.5



Note: Settled water chlorination refers to year-round chlorination.

Figure 5-1. Impact of DBP Control Strategies on Disinfection and Byproduct Formation

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6. Alternative Disinfection Benchmark

Some systems may not be able to meet Stage 1 DBPR MCLs while maintaining their existing disinfection practices and benchmark. Under these conditions, the system must consult with the State to discuss appropriate compliance strategies, including an alternative disinfection benchmark. The alternative disinfection benchmark would be lower than the calculated disinfection benchmark, allowing the utility greater flexibility to achieve compliance with DBPR MCLs while still not significantly compromising microbial protection. However, the alternative disinfection benchmark must not be lower than the disinfection requirements of the SWTR.

Each State will formulate its own plan for evaluating inactivation data and setting alternative disinfection benchmarks. The plan should foster cooperation between the State and water systems. The goal of an alternative disinfection benchmark is to improve a system's ability to meet the DBPR MCLs without significantly compromising existing microbial protection. The system and State should consider source water quality, existing physical barriers to pathogens, and the risk of waterborne disease to set an alternative disinfection benchmark. The information and examples presented here are intended as guidance. Each State should develop its own plan for evaluating and setting alternative disinfection benchmarks.

The following examples describe characteristics of systems that may choose to develop an alternative benchmark:

- Systems that cannot simultaneously meet the disinfection benchmark and the Stage 1 DBPR MCLs and which have:
  - very high levels of microbial inactivation and/or
  - high quality source water that has low pathogen occurrence levels.

These examples are not meant to be exhaustive. If a system has circumstances similar to the above examples, it may want to consult the State to set an alternative disinfection benchmark to gain greater flexibility for complying with the provisions of the Stage 1 DBPR.

Systems with Very High Levels of Microbial Inactivation

Some water systems have very high existing levels of inactivation. These high values may be the result of the following:

- The disinfectant dose is controlled by the need to maintain a residual in the distribution system rather than by the need to provide the primary disinfection required by the SWTR. The dose required to provide a distribution system residual often determines in-plant disinfection practices.

- To simplify compliance with the SWTR, a system may operate with a "minimum specified residual" under worst case operating conditions. Because the worst case conditions may not occur simultaneously (i.e., lowest temperature and greatest peak hourly flow rate), the utility may be achieving much greater disinfection levels than required by the SWTR.

- The disinfectant in use may be much more effective against a particular pathogen. For example, chlorine is much more effective at inactivating viruses than it is *Giardia*. For this reason, systems that inactivate *Giardia* with chlorine may be achieving very high logs inactivation of viruses (e.g., greater than 10 logs) as indicated by extrapolation using the CT concept. A system may want to apply for an alternative disinfection benchmark for viruses, if it is considering switching to another disinfectant or improving its physical removal processes.

- The treatment plant is operating well below design flow and, therefore, disinfection contact time is extremely long.

In the above examples, the benchmark inactivation for *Giardia* and/or viruses may be so high that the log inactivation levels would be well in excess of treatment needed. Therefore, there may be an opportunity to reduce the level of calculated inactivation without significantly increasing the risk of waterborne disease.

Systems Exceeding the Stage 1 DBP MCLs

It may be very difficult for some systems to maintain current levels of *Giardia* or virus inactivation and simultaneously comply with Stage 1 DBPR MCLs (0.080 mg/L and 0.060 mg/L for TTHM and HAA, respectively). These systems may want to set an alternative benchmark to obtain greater flexibility for DBPR compliance.

Consider a system that has been using free chlorine for primary disinfection and maintenance of a distribution system residual. The system is interested in switching to chloramines for residual disinfection in order to limit free chlorine contact time and control DBP formation. Chloramines are less effective for inactivating both *Giardia* and viruses. Therefore, if ammonia is added prior to the historical point of chlorine residual measurement, the level of primary disinfection would be diminished from historical practices (i.e., the system would fall below its existing disinfection benchmark). In this example the system could either increase the free chlorine residual to meet the existing benchmark or apply to the State for an alternative disinfection benchmark. Another option, presented earlier, is the seasonal use of chloramines, which may not require an alternative benchmark.

Systems with High Quality Source Water

Water systems with very stable and high quality source water (usually in well-protected watersheds) may have a lower risk of microbial occurrence. Disinfection of high quality water with low pathogen occurrence, beyond the requirements of the SWTR, may not be warranted provided that filtration is well operated and watershed control is practiced.

The SWTR requires all plants to provide at least 4-log inactivation and/or removal of viruses and 3-log inactivation and/or removal of *Giardia*. Because SWTR allows states to give credit for filtration, the log inactivation required by chemical disinfection can be significantly lower. The EPA recommends that the State allow more credits for *Giardia* and virus removal by filtration if the following applies (AWWA, 1991):

1. It is determined that the system is not currently at significant risk of microbiological contamination at the existing level of disinfection.
2. Less stringent interim disinfection conditions are necessary for the system to modify its disinfection process to optimally achieve compliance with the SWTR as well as forthcoming DBP regulations.

Table 6-1 presents the different log removal credits allocated for different types of filtration.

Table 6-1. Log Removal Credits for Filtration

Filtration	**Giardia Log Removal**	**Virus Log Removal**	**Conditions for Credit Allocation**
Conventional	2.5	2.0	Meets the following: A)Total treatment train achieves 1) at least 99% turbidity removal or filtered water turbidities are less than 0.5 NTU or 2) 99.9% particle removal in size ranges of 5 to 15 um is demonstrated; and B)The level of HPC bacteria in the filtered water entering the distribution system is consistently less than 10/mL.
Direct Filtration	2.0	1.0	Same conditions as above.
Slow-Sand Filtration	2.0	2.0	Same conditions as above.
Diatomaceous Earth Filtration	2.0	1.0	Same conditions as above.

Source: AWWA, 1991.

Figure 6-1 illustrates the potential range for alternative disinfection benchmarks. The daily log inactivation of *Giardia* or viruses over a period of time constitutes the disinfection profile. The disinfection benchmark, shown as a solid horizontal line on the profile, is the average of the lowest month of each year. Therefore, the benchmark is typically determined by the disinfection practiced in winter months (January and February in the profile shown). The level of inactivation required by the SWTR (assuming States grant a removal credit of 2.5-logs for conventional treatment and 2-logs for direct filtration) is shown as horizontal dashed lines on the figure for conventional and direct filtration. This log inactivation removal is determined by subtracting the physical removal credit for filtration from the total log inactivation/removal required by the SWTR. The bold arrows denote the range for alternative disinfection benchmarks. Alternative disinfection benchmarks are lower than existing disinfection benchmarks, but always must be equal to or greater than requirements of the SWTR.

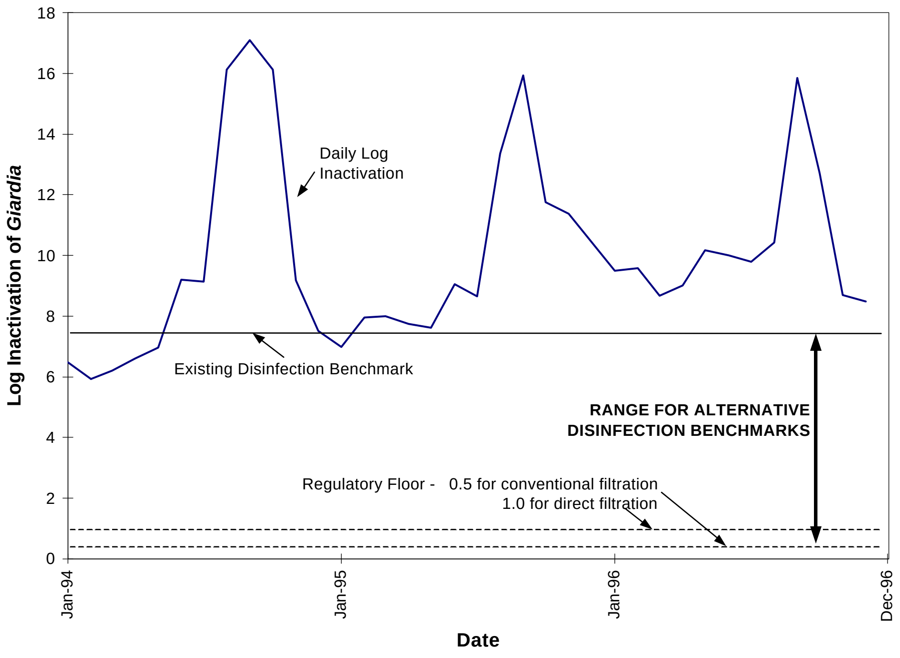

Figure 6-1. Range for Alternative Disinfection Benchmarks

6.1 Methodology

Options for developing the alternative disinfection benchmark are described below. These options are guidance only. The State may choose to adopt a methodology for setting alternative benchmarks based on this guidance or develop other methodologies. However, under no circumstances may the State set an alternative disinfection benchmark lower than disinfection level required by the SWTR.

The goal of the SWTR is to ensure that the annual risk of *Giardia lamblia* infection for an individual is less than 10^{-4} cases/person/year. The SWTR used an exponential risk assessment model (Rose, 1988) to calculate the logs of treatment necessary to keep the annual risk of infection below 10^{-4} cases/person/year for different concentrations of *Giardia lamblia* cysts in source water. EPA developed two options, or methodologies, for setting an alternative benchmark from this risk paradigm.

Cryptosporidium was not used as a reference for establishing alternative disinfection benchmarks because most systems currently employ disinfection which is assumed to provide little or no inactivation of this pathogen. Therefore, any change in disinfection practice is not addressed with respect to *Cryptosporidium*. These options are provided as guidance or recommendations only. Systems and States may use or modify these options or develop their own options.

Option 1 – No Monitoring

This option allows a utility to set an alternative disinfection benchmark without characterizing the quality of its source water. The lack of monitoring data requires the assumption that high levels of disinfection be provided. This option may be attractive to systems that have average source water quality, have high existing disinfection benchmarks, and do not need flexibility to meet the DBPR MCLs.

The goal of the SWTR is to limit infections by *Giardia* to one per year per 10,000 people (10^{-4} cases/person/year). This is assumed to be the maximum acceptable risk of infection. For source water having an average of 1 *Giardia* cyst per 100 L (very good quality water) and receiving 3-logs of treatment for *Giardia*, the risk of infection is about 10^{-4} cases/person/year. If one assumes a maximum *Giardia* concentration for source water of 100,000 per 100 L, then an 8-log removal/inactivation would be needed to maintain a 10^{-4} cases/person/year risk for *Giardia*. The 100,000 cysts per 100L concentration is approximately one order of magnitude higher than the highest *Giardia* cyst concentration known to be measured in source waters of drinking water supplies (LeChevallier et al., 1991b). The value of 8-logs is calculated by assuming that a finished water cyst concentration of 10^{-3} per 100L would be needed to achieve about a 10^{-4} risk of infection (cases/person/year) (Regli et al., 1991).

Table 6-2 applies to systems that need to set an alternative disinfection benchmark without the benefit of monitoring data. All systems that choose this option should achieve an 8-log treatment (combination of physical removal and chemical inactivation) for *Giardia* to meet the minimum acceptable risk. Assuming a 2.5-log physical removal by conventional filtration, 5.5-logs *Giardia* inactivation is the minimum alternative disinfection benchmark.

Table 6-2 also indicates minimum alternative disinfection benchmarks for viruses. These were derived assuming a maximum virus concentration in source waters of 10,000 per 100L and assuming that a viral concentration of 10^{-7} L would be needed to achieve a 10^{-4} risk level (Regli et al., 1991).

Credits for the physical removal of pathogens by filtration should be subtracted from the total treatment requirements to derive the level of treatment needed by chemical disinfection. The removal of pathogens is dependent on the organism of interest and the filtration process. Guidance for removal credits for filtration are provided in the Filtration Credit (logs) columns of Table 6-2, reprinted from the *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources* (AWWA, 1991).

Table 6-2. Alternative Disinfection Benchmarks for Systems Not Monitoring

	Giardia			**Virus**		
Filtration Process	Total Treatment Required (logs)*	Filtration Credit (logs)	Alternative Disinfection Benchmark (logs)	Total Treatment Required (logs)*	Filtration Credit (logs)	Alternative Disinfection Benchmark (logs)
Conventional	8.0	2.5	5.5	9.0	2.0	7.0
Direct	8.0	2.0	6.0	9.0	1.0	8.0
Slow Sand	8.0	2.0	6.0	9.0	2.0	7.0
Diatomaceous Earth	8.0	2.0	6.0	9.0	1.0	8.0

* Assuming source water *Giardia* concentration of 100,000/100 L and viral concentration of 10,000/100L.
Source: AWWA, 1991.

Option 2 – Source Water Characterization

For this option, a system monitors its source water quality for one year. The alternative benchmark is developed based on the quality of the source water. Source water is characterized by monitoring either *E. coli* or fecal coliform. Unfiltered systems already monitor for fecal coliforms as a requirement to avoid filtration and therefore could continue to monitor for fecal coliform to help set an alternative benchmark. Guidelines for source water characterization are presented later in this section. At the end of the sampling duration, the system determines the 90th percentile value for *E. coli* or fecal coliform concentration, and uses these measurements for the alternative disinfection benchmark.

Until better analytical methods are developed and tested for protozoa, EPA believes that *E. coli* or fecal coliforms are the best available indicator at this time since these parameters can be practically measured and indicate the potential for pathogen contamination in the source water. EPA also believes that guidelines for prescribing minimum level of total treatment, for purposes of establishing alternative disinfection benchmarks, can be reasonably prescribed based on *E. coli* or fecal coliform levels in the source water.

The SWTR specifies that unfiltered systems must have a running six month 90th percentile source water fecal coliform levels of less than 20/100 mL as one of the criteria for avoiding filtration. Similarly, such systems must also provide at least 3-log inactivation of *Giardia* through disinfection each day that water is delivered to customers. If the system fails to achieve 3-log inactivation any two or more days per month, the system is in violation of a treatment technique requirement for that month. If the violation occurs during a second month in any 12 consecutive months the system serves water to the public, then the system must install filtration unless the State decides that one of the violations was unusual and unpredictable. Filtration is triggered, regardless of the cause, after a third violation.

EPA believes that this minimum level of inactivation, as prescribed under the SWTR, is an appropriate alternative benchmark for unfiltered systems having an excess of 3-logs of inactivation for *Giardia* or 4-logs of inactivation for viruses.

EPA recommends a minimum alternative benchmark of 1-log inactivation of *Giardia* for systems using conventional treatment and 1.5-log inactivation of *Giardia* for systems using direct, slow sand, or diatomaceous earth filtration for filtered systems that want to lower their disinfection level below the benchmark. This is recommended if the source water 90th percentile for either *E. coli* or fecal coliforms is less than 20/100 mL based on one year of water with at least five samples taken each week. Similarly, EPA recommends a minimum alternative benchmark of 2.5-log virus inactivation for systems using conventional treatment or slow sand filtration and 3.5-log virus inactivation for systems using direct or diatomaceous earth filtration.

EPA believes that plant operations to meet the minimum alternative benchmark as described above and the new turbidity performance criteria in the IESWTR should prevent significant increases in microbial risk for systems choosing to change their disinfection practices while complying with the Stage 1 DBPR.

Systems with higher source water *E. coli* or fecal coliform concentrations should provide alternative benchmarks as indicated in Tables 6-2 and 6-3 and Figures 6-2 and 6-3. EPA developed the recommended proportions, presented in the above mentioned tables and figures, by first assuming the worst case source water concentrations (i.e., the 90th percentile) *E. coli* or fecal coliform concentrations of 20,000/100 mL would correspond to worst case *Giardia* concentrations of 100,000 per 100 L, and treat at such contamination levels, including 5.5-log *Giardia* inactivation for systems using conventional treatment, and 6-log *Giardia* inactivation for systems using direct, slow sand, or diatomaceous earth filtration. These inactivation levels would be needed to achieve the SWTR's 10^{-4} annual risk of infection goal, assuming the minimum *Giardia* physical removal credits recommended for filtration under the SWTR. EPA then assumed that proportional levels of disinfection treatment between the two sample points should provide a reasonable barrier of protection against microbial risk if systems wish to change their disinfection practices to comply with the Stage 1 DBPR.

Table 6-3 presents the recommended alternative disinfection benchmarks as a function of source water quality and the physical removal process employed. The values in the table have been interpolated between the two endpoints of poor and good water quality, and include the credits mentioned above for sedimentation and filtration. Once the system has determined its 90th percentile value of indicator organism in source water, it may use Table 6-3 to select the recommended minimum alternative disinfection benchmark.

A graphical representation of Table 6-3 is presented in Figures 6-2 and 6-3. These figures display the 90th percentile indicator concentrations on the y-axis, with recommended alternative disinfection benchmarks on the x-axis. The two lines on each figure represent the different filtration processes.

Table 6-3. Impact of Source Water Quality and Filtration Process on Alternative Disinfection Benchmark

	Giardia Alternative Disinfection Benchmark (log inactivation)		Virus Alternative Disinfection Benchmark (log inactivation)	
90th Percentile Indicator Concentration* (cfu/100ml)	**Conventional**	**Direct, Slow Sand, or Diatomaceous Earth**	**Conventional or Slow Sand**	**Direct or Diatomaceous Earth**
< 20	1.0	1.5	2.5	3.5
30	1.3	1.8	2.8	3.8
40	1.5	2.0	3.0	4.0
50	1.6	2.1	3.1	4.1
60	1.7	2.2	3.2	4.2
70	1.8	2.3	3.3	4.3
80	1.9	2.4	3.4	4.4
90	2.0	2.5	3.5	4.5
100	2.0	2.5	3.5	4.5
200	2.5	3.0	4.0	5.0
300	2.8	3.3	4.3	5.3
400	3.0	3.5	4.5	5.5
500	3.1	3.6	4.6	5.6
600	3.2	3.7	4.7	5.7
700	3.3	3.8	4.8	5.8
800	3.4	3.9	4.9	5.9
900	3.5	4.0	5.0	6.0
1,000	3.5	4.0	5.0	6.0
2,000	4.0	4.5	5.5	6.5
3,000	4.3	4.8	5.8	6.8
4,000	4.5	5.0	6.0	7.0
5,000	4.6	5.1	6.1	7.1
6,000	4.7	5.2	6.2	7.2
7,000	4.8	5.3	6.3	7.3
8,000	4.9	5.4	6.4	7.4
9,000	5.0	5.5	6.5	7.5
10,000	5.0	5.5	6.5	7.5
≥20,000	5.5	6.0	7.0	8.0

* Indicator concentration refers to either *E. coli* or fecal coliform.

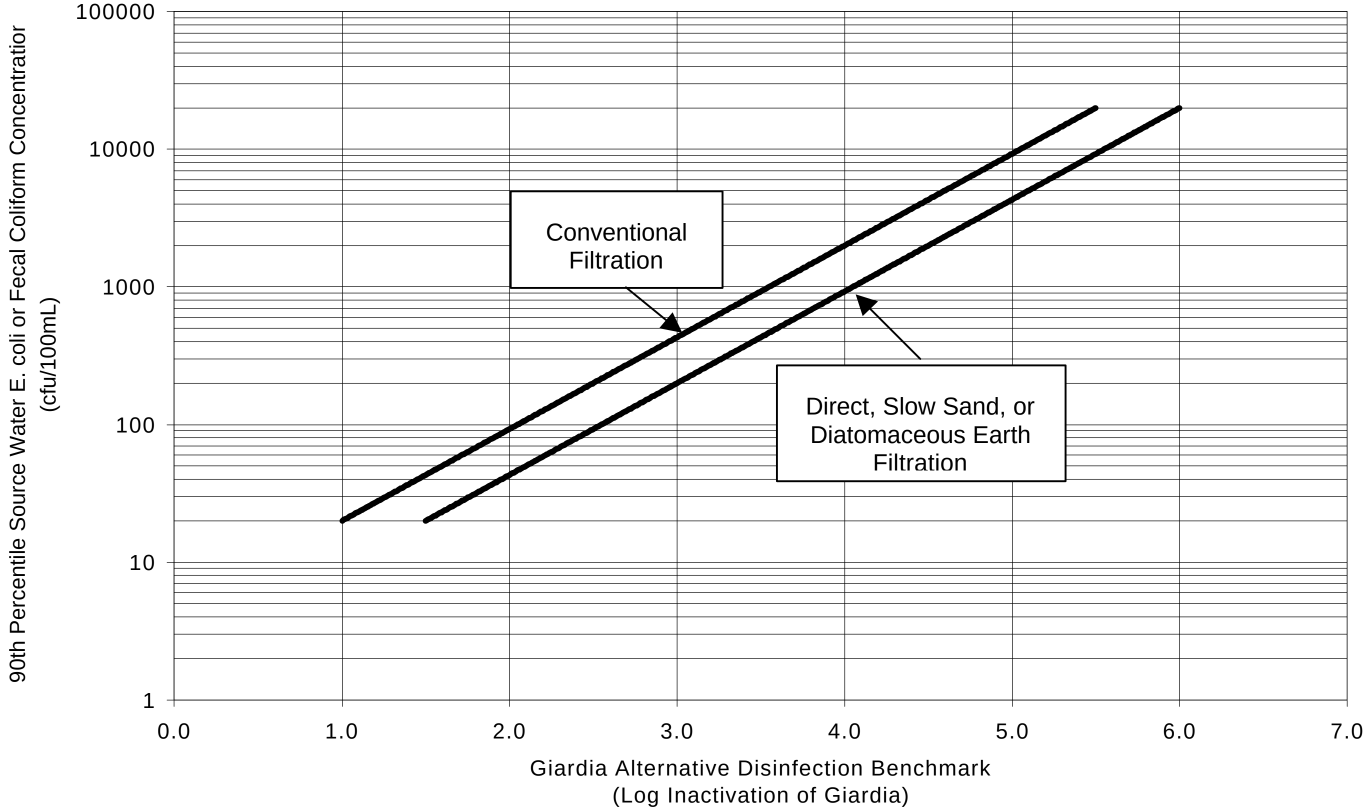

Figure 6-2. Impact of Source Water Quality and Filtration Process on *Giardia* Alternative Disinfection Benchmark

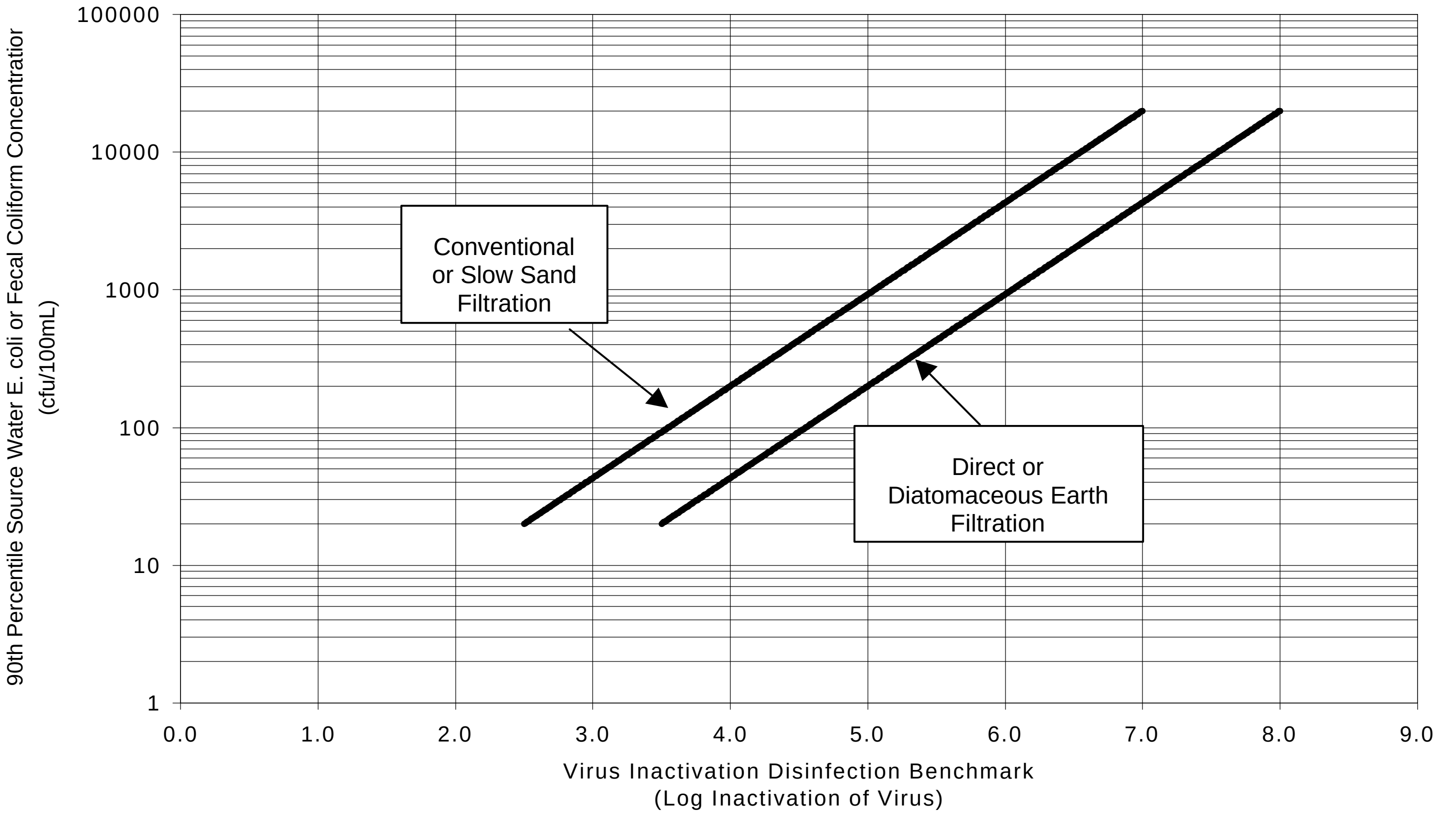

Figure 6-3. Impact of Source Water Quality and Filtration Process on Virus Alternative Disinfection Benchmark

Adjustment Factors

It may be appropriate for the State and system to consider adjusting the alternative disinfection benchmark based on qualitative factors. These factors would allow the State and system to increase or decrease the alternative disinfection benchmark based on information not considered in the methodology.

Examples of conditions that might be used by the State and system to increase the alternative disinfection benchmark:

- Upstream sewage discharge, combined sewer overflow (CSO), sanitary sewer overflow (SSO), contaminated stormwater, feedlots upstream
- Operational issues (e.g., variability of finished water quality)
- Variable source water quality
- Previous waterborne disease outbreaks
- Noncompliance with Total Coliform Rule.

Examples of conditions that might be used by the State and system to decrease the alternative benchmark:

- Excellent filter effluent quality (less than 0.1 NTU), especially with average raw water turbidities greater than 10 NTU
- Two-stages of physical treatment (e.g., conventional treatment and nanofiltration)
- Exceptionally low fecal coliform or *E. coli* levels (i.e., substantially less than the 20/100 mL cutoff) if the system is at the minimum indicated alternative disinfection benchmark
- Occasional use of ozone or other oxidants for taste and odor, iron, and manganese control
- Large credits for long contact times with water transported through transmission lines prior to treatment plant.

6.2 Schedule Guidance

The date for complying with Stage 1 DBPR and IESWTR is December 2001 (3 years after promulgation) for subpart H systems serving at least 10,000 people. Therefore, EPA recommends that a one-year source water monitoring program to support the development of an alternative disinfection benchmark begin in, or before, the last quarter of 2000. Waiting until the last quarter of 2000 would not be prudent, since it would not allow time to develop the alternative disinfection benchmark and implement and select a strategy to meet DBPR MCLs and the alternative benchmark. A system may want to proceed with TTHM, HAA5 monitoring and source water monitoring simultaneously rather than sequentially to provide the greatest flexibility for complying with all applicable rules. Table 6-4 shows a schedule that may allow systems to use Option 2 to develop an alternative disinfection benchmark and still provide time for a utility to implement a DBP control strategy that will meet the alternative disinfection benchmark by the compliance deadline.

Table 6-4. Example Schedule for Compliance with M-DBP Rules

	1999				2000				2001				2002			
DBPR and IESWTR Compliance Task	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Source Water Characterization		↔	↔	↔	↔											
Profile/benchmark/State consultation						↔	↔	↔	↔							
Apply State-approved Alternative Disinfection Benchmark										↔	↔	↔	↔	↔	↔	↔
Implement Improvements/ changes (if needed)										↔	↔	↔	↔	↔	↔	↔

6.3 Source Water Characterization

Source water characterization used to develop an alternative disinfection benchmark includes sample collection, sample analysis, data evaluation and reporting. The objective is to characterize the source water, prior to any treatment, in terms of either fecal coliform or *E. coli* concentrations. Elevated concentrations of fecal coliform and *E. coli* in surface water indicate a greater probability of contamination by pathogens. Understanding the quality of the source water allows the State and water system to select an appropriate level for the alternative disinfection benchmark.

Sample Collection. Water systems collect five water samples per week, on different days, for one year. The one-year monitoring period will assess seasonal differences in source water character. If five samples per week are collected and analyzed over a 52-week calendar year, the water system will have 260 data values at the end of the year.

Source water samples should be collected at a location prior to treatment. At this location, the water should not be subject to surface runoff. It is not appropriate for systems to collect samples downstream from the addition of a disinfectant or oxidant. In addition, it is not appropriate for systems to collect samples downstream of coagulation/sedimentation or filtration.

The samples should be collected by the grab method using sterile whirlpack bags, sterile plastic, or sterile glass containers. The volume required is less than 100 ml (120 ml bottles are standard bacteriological sampling bottles), but the laboratory should be contacted for verification. No chemical preservative is required, but the sample should be stored in an iced cooler. Sample temperature should be between 1 and 4.4°C during transportation and samples should be stored in the dark. The sample must not be held more than 6 hours prior to laboratory analysis (Standard Methods, 1995).

Sample Analysis. The fecal coliform and *E. coli* samples should be analyzed using one of four analytical methods identified in EPA National Primary Drinking Water Regulations, 40 *CFR* 141.21(f)(6)(i-iv). The methods include:

1. An extension of Method 9221E described in Standard Methods (1995)
2. An extension of Method 9221B using nutrient agar
3. Minimal medium ONPG-MUG Test documented by Edberg, et al. (1988).
4. The Colisure Test by Milipore Corporation, Technical Services Department, 80 Ashby Road, Bedford, MA 01730.

Data Evaluation. In any week, the system should obtain five values for indicator organism concentrations corresponding to five different days of that week. If a system misses the collection of a value, the system should record the letter “M” for missing data, for the day of the week that the data value was not collected. Therefore, in any week, the utility will obtain five values, some of which will be the letter “M” if data are missing. Systems are encouraged to collect all 260 values and not to have missing values. Values that are missed are assumed to have poor water quality and count against the system when developing the alternative disinfection benchmark.

In general, data on concentrations of microbiological organisms in water from streams, lakes, and reservoirs often exhibit a large number of samples with very low concentrations and a few samples with high concentrations. Thus, the average or mean concentration is not a very good measure on the expected concentrations because of the few large values. For this reason, a distribution frequency (percent of samples above or below a specified value) is more meaningful. For setting the alternative disinfection benchmark, EPA recommends the 90th percentile value.

To determine the 90th percentile value the data should be sorted from the largest value to the smallest value recorded (regardless of the date of collection). All of the “M,” or missing values, should be placed at the top of the list. The result of this action should be a list of the top 26 data values of the 260 total values with missing values at the top of the list followed by the largest numerical values that decrease to the smallest value at the bottom of the list. The 90th percentile value is found by locating the 26th number of the list. It is this 90th percentile value that characterizes the quality of the source water for developing the alternative disinfection benchmark.

As part of the consultation with the State, the system may want to explain why samples were missed (e.g., sample container lost or samples not analyzed in a timely manner). The system may then be able to develop a different 90th percentile by dropping missed samples from the calculation.

Use of Historical Database. Some systems may already monitor their source water for fecal coliform and *E. coli*. The resulting historical database may be sufficient for the State and system to develop an alternative disinfection benchmark. The historical database is considered sufficient for making this determination if:

- The raw water sampling location is upstream from the point of any treatment
- At least five samples per week are collected on different days
- The sampling period covers at least one year
- Methods of analysis are consistent with those presented herein.

6.4 Watershed Control Program

A watershed control program is a surveillance and monitoring program that is conducted to protect the quality of a surface water source. An aggressive and detailed watershed control program is desirable to effectively limit or eliminate potential contamination by microbial pathogens. A watershed program may impact parameters such as turbidity, certain organic compounds, viruses, total and fecal coliforms, *Giardia*, *Cryptosporidium*, and areas of wildlife habitation. However, the program is expected to have little or no impact on parameters such as naturally occurring inorganic chemicals. Limiting human activity in the watershed may reduce the likelihood of animals becoming infected with pathogens and thereby reduce the transmission of pathogens by wildlife. Preventing animal activity near the source water intake prior to disinfection may also reduce pathogen occurrence at the intake.

The effect of a watershed program is difficult to quantify since many variables that influence water quality are beyond the control or knowledge of the water supplier. As a result, the benefit of a watershed control program or specific control measures must in many cases be based on accumulated cause and effect data and on the general knowledge of the impact of control measures rather than on actual quantification. The effectiveness of a program to limit or eliminate potential contamination by microbial pathogens will be determined based on: the comprehensiveness of the watershed review; the ability of the water system to effectively carry out and monitor the management decisions regarding control of detrimental activities occurring in the watershed; and the potential for the water system to maximize land ownership and/or control of land use within the watershed. Under the SWTR, a watershed control program should include as a minimum:

- A description of the watershed including its hydrology and land ownership
- Identification, monitoring and control of watershed characteristics and activities in the watershed which may have an adverse effect on the source water quality
- A program to gain ownership or control of the land within the watershed through written agreements with landowners, for the purpose of controlling activities which will adversely affect the microbiological quality of the water
- An annual report which identifies special concerns in the watershed and how they are being handled, identifies activities in the watershed, projects adverse activities expected to occur in the future and how the utility expects to address them.

Appendix J of the *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources* (AWWA, 1991) contains a more detailed guide to a comprehensive watershed program.

In preparing a watershed control program, surface water systems should draw upon the State watershed assessments and non-point source (NPS) pollution management programs required by §319 of the Clean Water Act. Information on these programs is available from State water quality agencies or EPA's regional offices. Assessments identify NPS pollutants in water and assess the water quality. Utilities should use the assessments when evaluating pollutants in their watershed. Surface water quality assessments can also be obtained from the lists of waters prepared under §304(1) of the Clean Water Act, and State biennially prepared §305(b) reports.

State NPS management programs identify best management practices (BMPs) to be employed in reducing NPS pollution. These management programs can be incorporated in the watershed program to protect against degradation of the source water quality.

For systems using ground water sources under the influence of surface water, the control measures delineated in the Wellhead Protection (WHP) program encompass the requirements of the watershed control program, and can be used to fulfill the requirements of the watershed control program. Guidance on the content of Wellhead Protection Programs and the delineation of wellhead protection areas is given in *Guidance for Applicants for State Wellhead Protection Program Assistance Funds Under the Safe Drinking Water Act* (USEPA, 1987a) and *Guidelines for Delineation of Wellhead Protection Areas* (USEPA, 1987b), available at www.epa.gov/OGWDW000/whpnp.html.

As a minimum, the WHP program must:

- Specify the duties of State agencies, local governmental entities and public water supply systems with respect to the development and implementation of Programs.
- Determine the wellhead protection area (WHPA) for each wellhead as defined in subsection 1428(e) based on all reasonably available hydrogeologic information, ground water flow, recharge and discharge and other information the State deems necessary to adequately determine the WHPA.
- Identify within each WHPA all potential anthropogenic sources of contaminants which may have any adverse effect on the health of persons.
- Describe a program that contains, as appropriate, technical assistance, financial assistance, implementation of control measures, education, training and demonstration projects to protect the water supply within WHPAs from such contaminants.
- Present contingency plans for locating and providing alternate drinking water supplies for each public water system in the event of well or wellfield contamination by such contaminants.
- Consider all potential sources of such contaminants within the expected wellhead area of a new water well which serves a public water supply system.
- Provide for public participation.

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