3. CREATING A PROFILE: DATA REQUIREMENTS AND CALCULATIONS

Disinfection profiling is the characterization of a water system's practices (log inactivation) over a period of time. Appendix B presents a discussion on the development of log inactivation methods under the SWTR and an example on how to calculate log inactivations. The disinfection profile is a graphical representation of the magnitude of daily *Giardia* or virus inactivations which is developed, in part, based on daily measurements of the following operational parameters:

- Disinfectant residual concentrations
- Peak hourly flow rate
- Temperature
- pH (chlorine only).

For purposes of complying with the requirements of the IESWTR, a profile can be prepared from historical treatment plant operating data, if adequate data are available, or the profile may have to be prepared using data acquired in a new monitoring program.

As noted in Chapter 2, depending on the disinfectant employed, the IESWTR requires profiles for either *Giardia* or *Giardia* and virus. The basic data requirements for creating a profile based on *Giardia* or virus are the same. Therefore, if a utility collects operating data sufficient to profile for *Giardia*, it can also develop a profile for viruses with only slight modifications to the calculations described in this chapter.

3.1 Data for Profiling

The IESWTR provides direction on operational data needed for calculating the disinfection profile. If approved by the State, existing historical (i.e., grandfathered) operational data may be used for this purpose. If a system does not have three years of approved grandfathered data, then it must conduct additional monitoring of operational data to meet the requirements of the IEWSTR. The system may develop a profile using a combination of both grandfathered data (where less than three years of approved data are available) and new data. This section provides guidance on the use of grandfathered data, the need for conducting additional monitoring, the required quality of the existing data, and the State's role in approving the use of available operational data.

Water systems should not use existing data if these data do not accurately represent the system's current level of disinfection. For example, existing data should not be used for systems that have recently made significant modification to their disinfection practices. A significant modification includes changes in disinfectants or changes in plant hydraulics or piping schemes that affect disinfection contact time. These treatment train modifications

may substantially impact the level of inactivation provided as indicated by the CT and render existing data unrepresentative of the system's current inactivation performance. CT, in mg-min/L, is the product of C (the residual disinfectant concentration in mg/L) and T, (the time that water is in contact with the disinfectant in minutes).

3.1.1 Operational Data Required for Profiling

The IESWTR requires systems with less than three years of applicable data to conduct daily monitoring for profiling. As required in the IESWTR, the following data must be gathered daily at peak hourly flow at each disinfectant residual sampling point in the treatment plant:

- Disinfectant residual concentration in the treatment plant
- Peak hourly flow rate
- Temperature
- pH (if the system uses chlorine).

For systems with more than one point of disinfectant application, the same data must be collected at least daily at each of the disinfectant residual sampling points (i.e., segments). Section 3.2.2 provides a detailed description of acceptable water quality data analysis methods. Section 3.3.1 and Appendix D contain detailed descriptions of segments.

The time that the disinfectant is in contact with water in the disinfection segment must be determined on a daily basis to complete the CT calculations. This contact time, measured as T_{10}, is determined based on the peak hourly flow rate occurring during the 24-hour period and the detention time that is equaled or exceeded by 90 percent of the water passing through the basin. This procedure is detailed in Appendix D. States may allow systems to use non-peak flow measurements, but EPA is convinced that such measurements will result in a higher inactivation and may result in a higher benchmark.

3.1.2 Data Quantity

The IESWTR requires systems to create a disinfection profile that covers a minimum of 12 consecutive months. The profile may span a maximum of 36 consecutive months. All systems will therefore need one- to three- years of data to calculate daily log inactivations. Existing data may be used if the State determines that the quality of the data is sufficient. Under the IESWTR, systems without three years of existing acceptable operational data are required to monitor for one additional year.

Systems required to develop disinfection profiles under this rule must exercise one of the following three options:

- Option 1 - Systems must conduct daily monitoring as described below. This monitoring must be completed no later than March 2001 and must cover a period of one year. The data collected from this monitoring must be used to develop a one-year disinfection profile.

- Option 2 -Systems that conduct monitoring under this rule, as described under Option 1, may also use one or two years of acceptable grandfathered data, in addition to the one-year of new operational data, in developing the disinfection profile.
- Option 3 -Systems that have three years of acceptable existing operational data are not required to conduct monitoring to develop the disinfection profile under this rule. Instead, they may use grandfathered data to develop a three-year disinfection profile. Systems must coordinate with the State to confirm acceptability of grandfathered data no later than March 2000, but must conduct the required monitoring until the State approves the system's request to use grandfathered data.

3.1.3 Data Quality

As noted above and in the IESWTR, existing data may be used by systems to calculate disinfection profiles if the data are approved by the State. For existing data to be acceptable to the State, the data must be "substantially equivalent" to the quality of CT data prescribed in the existing SWTR and in this guidance manual.

Substantially equivalent data are data that meet the sampling location, handling, and analytical method requirements described in this guidance manual and the *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources* (AWWA, 1991). The data should accurately characterize disinfection throughout the treatment plant. Detailed descriptions of acceptable methods for collecting the required data are provided in Sections 3.2 and 3.3 of this guidance manual. For systems that have recent recorded their daily log inactivation calculations, the State should verify the accuracy of these calculations as part of its data review and acceptance process.

3.2 Procedure to Determine Log Inactivation

This section provides an overview of the procedure to calculate CT values to determine log inactivation as designed under the SWTR and for disinfection profiling.

3.2.1 Use of CT Values for Disinfection Profiling

The CT method is used to evaluate the amount of disinfection a treatment plant achieves and to determine compliance with the SWTR. The SWTR requires physical removal and/or inactivation of 3-logs of *Giardia* and 4-logs of viruses. For disinfection profiling and benchmarking, the CT approach will be used to compute the log inactivation of *Giardia* or viruses achieved during water treatment.

The CT values corresponding to 3-log *Giardia* and 4-log viral inactivations are the basis for determining the estimated log inactivation achieved by the plant on any given day. Operational information required to use the SWTR CT tables include: disinfectant type, temperature, pH (for chlorine only), and residual disinfectant concentration. Using this

operating information, the CT value corresponding to inactivations of 3-logs of *Giardia* ($CT_{3\text{-log, }Giardia}$) and 4-logs of viruses ($CT_{4\text{-log, virus}}$) can be read from the SWTR CT tables. These CT values are used to determine the estimated log inactivation achieved by applying a disinfectant to water.

The SWTR CT tables are provided in Appendix C for reference. These tables contain CT values corresponding to specified log inactivations of *Giardia* or viruses.

3.2.2 Steps to Calculate Log Inactivation

To construct a disinfection profile, actual treatment plant inactivations need to be determined using the SWTR CT tables. Data must be representative of the entire treatment plant, from the initial point of disinfectant/oxidant addition to the entrance to the distribution system; and is not limited to the segments used for compliance with the inactivation requirements of the SWTR.

Estimated log inactivations are calculated for each disinfection segment of the treatment train. Once the log inactivations for each segment are calculated, they are summed to yield the total plant log inactivations. The following steps, which are described in greater detail in subsequent sections of this chapter and are shown in Figure 3-1, provide the general procedure for calculating the estimated log inactivations to generate disinfection profiles:

- Systems measure the following operational data each day at each disinfectant residual sampling point (Section 3.3):
  - Disinfectant residual concentration (C, in mg/L)
  - Water temperature (°C)
  - Water pH (for systems using chlorine).
- Systems determine the peak hourly flow rate for each day from flow monitoring records. The systems calculate contact time (T_{10}) for each disinfection segment based on baffling factors or tracer studies ***(Section 3.4).***
- Systems calculate CT_{actual} for each disinfection segment under actual operating conditions (i.e., C x T_{10}) ***(Section 3.4).***
- Systems determine the CT required for 3-log *Giardia* inactivation ($CT_{3\text{-log, }Giardia}$) and/or 4-log virus inactivation ($CT_{4\text{-log, virus}}$) from the SWTR CT Tables ***(Section 3.4 and Appendix C).*** These required CT values are dependent on the disinfectant type, residual concentration, temperature, and pH.
- Systems calculate the estimated log inactivation for *Giardia* and/or viruses for each disinfection segment ***(Section 3.4)*** using:
  - Segment log inactivation of *Giardia* = 3.0 * CT_{actual} / $CT_{3\text{-log, }Giardia}$
  - Segment log inactivation of viruses = 4.0 * CT_{actual} / $CT_{4\text{-log, viruses}}$

- Systems sum the segment log inactivations to determine the plant log inactivations due to chemical disinfection (the segment log inactivation are additive) ***(Section 3.4)*** using:
  - Plant log inactivation of *Giardia* = $\sum$ (segment log inactivation of *Giardia*)
  - Plant log inactivation of viruses = $\sum$ (segment log inactivation of viruses)

Figure 3-1 provides a schematic of the disinfection profiling methodology based on the log inactivation method.

3.2.3 Determining Disinfectant Residual Concentrations, pH, and Temperature

The disinfectant residual concentration is defined as the concentration of disinfectant used to protect the distribution system from recontamination. This residual is measured, along with temperature and pH, at a location referred to as the "residual sampling point." If a treatment plant has three disinfection segments it will therefore, have three residual sampling points that must be measured. Disinfection segments are further defined in Section 3.3.1.

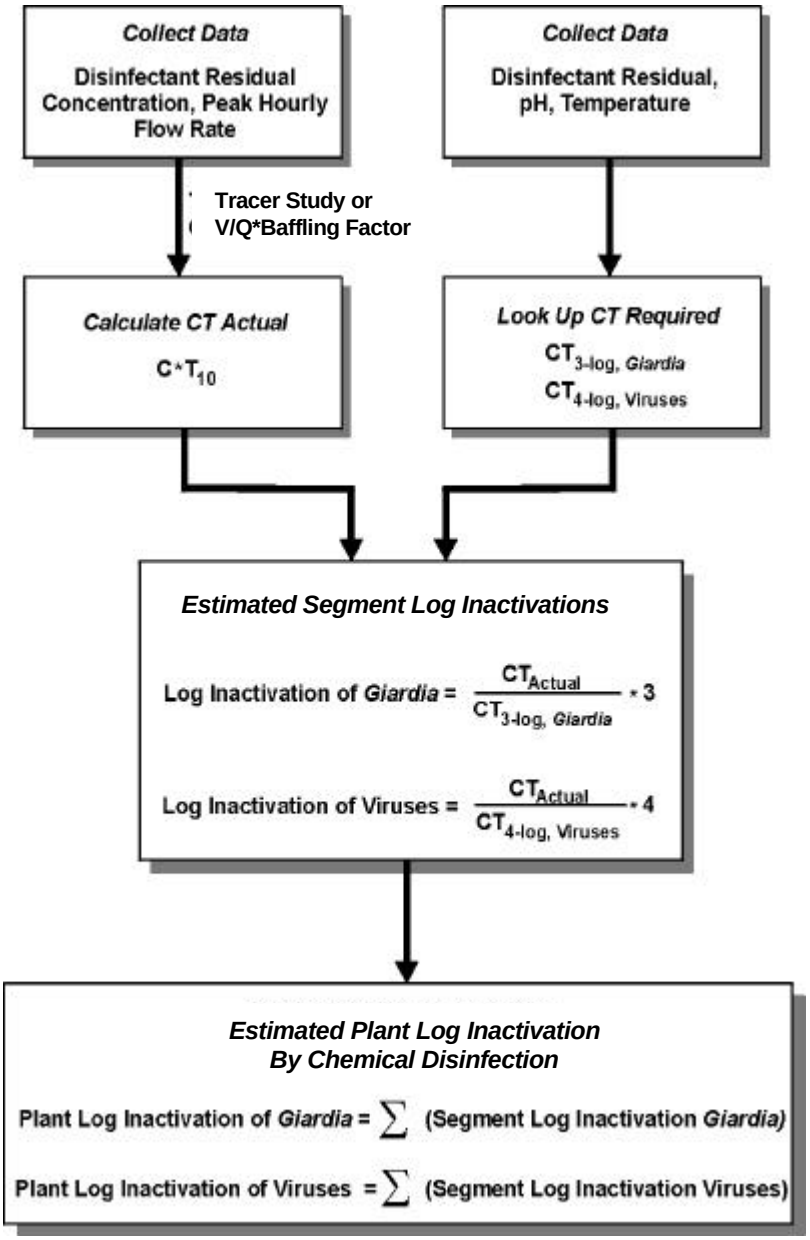

Figure 3-1. Disinfection Profiling Methodology

Table 3-1. Acceptable Laboratory Methods for Analyses

Parameter	Acceptable Method(s)[1]	Examples of Commercial Test Kits/Equipment[2]
Temperature[3]	Thermometric (SM 2550)	Any good, mercury-filled thermometer but thermocouples are acceptable
pH[3]	Electrometic (SM 4500-H+) Electrometic (EPA A50.1&2)	Hach EC series & One series LaMotte DHA 3000 Orion A series & 300 series
Free Chlorine	Amperometric, Titration (SM 4500-Cl D)	Hach Amperometric Titrator Fischer-Porter 17T200 Capital Controls 1870E (on-line monitor) Great Lakes 95CL (on-line monitor)
	DPD Ferrous, Titration (SM 4500-Cl F)	LaMotte 6806/DT
	DPD, Colorimetric (SM 4500-Cl G)	Hach DR100, DR700 & DR/2000 Hach Pocket Colorimeter LaMotte DC-1100Cl LaMotte SMART Colorimeter Hach CL17 (on-line monitor)
	Syringaldizine (FACTS) (SM 4500-Cl H)	
Chloramine	Amperometric, Titration (SM 4500-Cl D)	Hach Amperometric Titrator Fischer-Porter 17T200 Capital Controls 1870E (on-line monitor) Great Lakes 95CL (on-line monitor)
	DPD Ferrous, Titration (SM 4500-Cl F)	LaMotte 6806/DT
	DPD, Colorimetric (SM 4500-Cl G)	Hach DR100, DR700 & DR/2000 Hach Pocket Colorimeter LaMotte DC-1100Cl LaMotte SMART Colorimeter Hach CL17 (on-line monitor)
Chlorine Dioxide	Amperometric, Titration (SM 4500-ClO_2 E) Amperometric, Titration (SM 4500-ClO_2 D)	Hach Amperometric Titrator Fischer-Porter 17T200 (Note: Platinum-Platinum electrodes are required.)
	DPD-Glycine (SM 4500-ClO_2 D)	LaMotte DC1100-CLO
Ozone	Indigo Method (SM 4500-O_3 B)	Hach DR/2000 & DR/4000 (Note: Spectrophotometric procedure is required.)

[1] SM – *Standard Methods* (1995); EPA – EPA Methods, 1995.
[2] This is not a complete list of all commercially available test kits nor an endorsement of any specific product.
[3] Samples must be analyzed prior to changes in character (e.g., sample allowed to warm prior to taking temperature)

3.2.4 Determining Contact Time, T_{10}

The contact time or detention time, T_{10}, is the value estimated using the theoretical detention time (TDT) and baffling factors or from data collected from a tracer study.

As discussed in Section 3.3.1, the treatment train may be divided into several disinfection segments, corresponding to the number of disinfectant application points. The disinfection segments may include several unit processes of the treatment train. The total T_{10} for the disinfection segment is the sum of each T_{10} for each unit process within the segment. The T_{10} can also be calculated for the whole plant or an entire segment instead of for individual segments, as long as there are no additional points of disinfectant addition.

The segment T_{10} is multiplied by the disinfectant residual at the end of the segment to yield the segment CT_{actual}. Section 3.4 provides an example of segmenting the treatment train and the corresponding CT calculations.

There are two methods to determine the contact time for a treatment process. The first method calculates contact time by utilizing the hydraulic characteristics of the treatment basin and baffling factors. These baffling factors are shown in Appendix D or may be available from the State. The second method involves conducting a tracer study for each disinfection segment. Baffling factors are used to determine T_{10} from theoretical detention times in systems when it is impractical to conduct tracer studies. These two methods and their use are discussed in detail in Sections 3.2.4.1 and 3.2.4.2.

Tracer Studies versus Baffling Factors

Tracer studies are more accurate than baffling factors as they provide a real measure of the contact time by measuring the time it takes for the tracer to flow through each segment in the treatment train. Tracer studies provide a better understanding of how well the disinfectant is mixing with the water for the hydraulic conditions of a specific water treatment plant. The disadvantage of the tracer study is that it is costly to conduct. The baffling factor method is a useful alternative for determining the contact time. It is less labor intensive, inexpensive, and easy to perform. The disadvantage, however, is that the baffling factors may not accurately represent the actual contact time of the system.

A conservative approach to calculating the contact time with baffling factors is to select the lowest baffling condition that is applicable. Baffling conditions include: very poor, poor, average, superior, or perfect. If it is not clear whether the baffling condition for a basin is average or superior, then the conservative approach is to use the average condition for the T_{10} calculations.

Contact Time for Unit Process

The unit processes that comprise each disinfection segment may include sedimentation, filtration, and pipeline flow, among others. Each of these reactors has special hydraulic characteristics affecting the contact time. In pipelines, the contact time can be assumed equivalent to the theoretical detention time and is calculated by dividing the internal volume of the pipeline by the peak hourly flow rate through the pipeline. Pipeline flow is assumed to be plug flow with no dead zones or unutilized volume in the reactor. Therefore, each unit of water is assumed to spend the same time in the pipeline, referred to as the TDT. For reactors of other shapes (e.g., a rectangular sedimentation basin) the time spent by the water in the reactor may vary over a range. For example, some water may move faster by short-circuiting while other water may spend more time in the reactor trapped in "dead zones" resulting in little flow. This variation in the time that water could spend in a particular unit process leads to a distribution of potential residence times from which T_{10} can be determined.

Contact Time for Pipe Flow

The contact time calculation for pipe flow is simply the theoretical detention time, which is the volume (V, in gallons) divided by the peak hourly flow rate (Q, in gallons per minute (gpm)),

$$T_{10} = \text{Contact Time} = V/Q \text{ (applicable to pipe flow only)}$$

Pipe flow does not require a tracer study to calculate contact time. The baffling factor for pipe flow is 1.0.

The following example of pipe flow assumes the pipeline to be 2,800 feet long and to have a cross-sectional area of 18 square feet (calculated from its inside diameter). The peak hourly flow rate in the pipeline is 10,651 gpm. The volume of water contained within the full pipeline is the length multiplied by the cross-sectional area. The resulting volume is:

$$\text{Volume, } V = 2800 \text{ feet} * 18 \text{ feet}^2 = 50{,}400 \text{ ft}^3$$

Converting the volume to gallons,

$$V = 50{,}400 \text{ ft}^3 * 7.48 \text{ gallons}/1 \text{ ft}^3 = 376{,}992 \text{ gallons}$$

Calculating the contact time,

$$T_{10} = V/Q = 376{,}992 \text{ gallons} / 10{,}651 \text{ gpm}$$
$$T_{10} = 35.4 \text{ minutes}$$

Contact Time in Mixing Basins and Storage Reservoirs

In mixing basins and storage reservoirs, the theoretical detention time generally does not represent the actual disinfectant contact time because of short-circuiting. Thus, determining contact time is more complicated with basins.

The time used to compute CT_{actual} in treatment basins depends on the reservoir shape, inlets, outlets, and baffling. Most clearwells and some other treatment basins were not designed to provide optimal hydraulic characteristics for contact with a disinfectant. Utilities are required to determine the contact time in mixing basins, storage reservoirs, and other treatment plant unit processes for the calculation of CT_{actual} through tracer studies or other methods approved by the State. For the purpose of determining compliance with the disinfection requirements of the SWTR, the contact time of mixing basins and storage reservoirs used in calculating CT_{actual} should be the detention time in which 90 percent of the water passing through the unit is retained within the basin, (i.e., T_{10}). Information provided by tracer studies is used for estimating the detention time T_{10} for the purpose of calculating CT_{actual}. If tracer studies are not practical, the TDT and baffling factor approach can be used. In Appendix D, complete descriptions of both the TDT and baffling factor method and the tracer test method to evaluate T_{10} are provided. A plant with multiple treatment trains and different operating characteristics should have the critical train identified.

3.2.4.1 Determining Contact Time Using Baffling Factors

The TDT is computed by dividing the volume of a unit process by the peak hourly flow rate (TDT=V/Q). Baffling factors (T_{10}/T) selected for a specific unit process are multiplied by the theoretical detention time to yield an estimate of the contact time, T_{10}, as follows:

$$T_{10} = \text{Contact Time} = V/Q * T_{10}/T$$

Table 3-2 describes baffling classifications and baffling factors (T_{10}/T ratios). The baffling factor is a function of design of the basin. A baffling factor of 1.0 represents plug flow characteristics. In plug flow, the TDT is equivalent to the contact time, T_{10}. Design modifications that can increase T_{10} may allow the same inactivation (CT) with a decreased disinfectant residual.

Table 3-2. Baffling Classifications and Factors

Baffling Condition	T_{10}/T	Baffling Description
Unbaffled (mixed flow)	0.1	None, agitated basin, very low length to width ratio, high inlet and outlet flow velocities
Poor	0.3	Single or multiple unbaffled inlets and outlets, no intra-basin baffles
Average	0.5	Baffled inlet or outlet with some intra-basin baffles
Superior	0.7	Perforated inlet baffle, serpentine or perforated intra-basin baffles, outlet weir or perforated launders
Perfect (plug flow)	1.0	Very high length to width ratio (pipeline flow), perforated inlet, outlet, and intra-basin baffles

Source: AWWA, 1991.

Using the following example information, the TDT can be calculated:

- Volume of a contact basin = 500,000 gallons
- Peak hourly rate = 10,000 gpm
- Contact basin = unbaffled.

The TDT is then calculated as follows:

$$TDT = V/Q = 500{,}000 \text{ gallons}/10{,}000 \text{ gpm} = 50 \text{ minutes}$$

However, because the contact basin is unbaffled, the T_{10}/T is 0.1 and the resulting actual contact time used for determining log inactivation is:

$$T_{10} \text{ (contact time)} = 50 \text{ minutes} * 0.1 = 5 \text{ minutes}$$

The CT value for this unit process at 1.2 mg/L residual chlorine is:

$$CT = 5 \text{ minutes} * 1.2 \text{ mg/L} = 6 \text{ mg-min/L}.$$

By improving contact conditions through inlet and outlet and some intra-basin perforated baffles, the T_{10}/T may improve to 0.7 and, therefore, the new contact time is:

$$T_{10} \text{ (contact time)} = 50 \text{ minutes} * 0.7 = 35 \text{ minutes}.$$

The new CT value at 1 mg/L of chlorine is:

$$CT = 35 \text{ minutes} * 1.2 \text{ mg/L} = 42 \text{ mg-min/L}$$

At a pH value of 6.0 and a water temperature of 15°C, the CT value needed to achieve a 2-log inactivation of *Giardia* by free chlorine (Table C-4, Appendix C) is 35 mg-min/L. At a pH value of 6.0 and a water temperature of 15°C the CT value needed to achieve 2.5-log inactivation of *Giardia* by free chlorine (Table C-4, Appendix C) is 44 mg-min/L.

To determine the estimated *Giardia* log inactivation for the CT value of 42 mg-min/L, linear interpolation may be used as follows:

Estimated Log removal = (42 mg-min/L * 2.5 logs) / 44 mg-min/L = 2.4

or

Estimated Log removal = (42 mg-min/L * 2 logs) / 35 mg-min/L = 2.4

In order to determine the contact time using baffling factors, the following steps ought to be taken:

- Determine peak hourly flow rate, Q, based on operation records;
- Determine the volume of each unit process;
- Calculate the TDT, where TDT = V/Q;
- Determine the baffling factor based on the unit processes baffling conditions, T_{10}/T;
- Calculate the contact time, where T_{10} = TDT * T_{10}/T; and
- Determine the segment T_{10} by summing each T_{10} of the unit processes in the segment.

3.2.4.2 Determining Contact Time Using a Tracer Study

A tracer study uses a chemical tracer to determine the detention time of water flowing through a unit process, segment, or system. Typical chemical tracers include chloride ions, fluoride ions, and a fluorescent dye Rhodamine WT. Ideally, the selected tracer chemical should be readily available, easily monitored, and acceptable for use in potable water supplies. The tracer should also be conservative (i.e., the tracer is not consumed or removed during treatment). Fluoride ions can generally be used in lower concentrations than chloride because they are typically present in lower concentrations in the water. Rhodamine is a fluorescent tracer that, if selected, must be used following certain guidelines found in Appendix D. Selection of a particular chemical tracer may depend on the unit processes and the salt concentrations present in the water. Specific instructions on chemical tracers and under what conditions are they most effective are found in Appendix D. If a tracer study is needed in order to find T_{10}, a water system should consult the latest tracer study guidance from the State.

The tracer chemical should be added at the same points in the treatment train as the disinfectant to be used in the CT calculations, since it will be used to determine T_{10} for the disinfection segment. Two common methods of tracer addition are the step-dose method and the slug-dose method. In the step-dose method, the tracer chemical is injected at a constant dosage and the endpoint concentration is monitored. To determine a 90 percent recovery for the tracer, endpoint sampling should continue until the tracer concentration reaches a steady-state level. With the slug-dose method, a large dose of tracer chemical is instantaneously injected. An effective way to achieve instantaneous addition is to use a gravity-fed tube to release the single dose. The tracer concentration is monitored at the endpoint, until the entire dose has passed through the system. Unlike the step-dose method, a mass balance is required to determine whether the entire tracer dose was recovered. Additional mathematical manipulation is required to determine T_{10} from the concentration versus time profile.

The test procedure for determining the contact time with a tracer study is generally as follows:

- The system determines the flow rate or rates to be used in the study.
- The system selects the tracer chemical and determines the raw water background concentration of the tracer chemical. The background level is needed to both determine the quantity of chemical to feed and to evaluate the data properly.
- The system determines the tracer addition locations, plans the sample collection logistics and frequency, and determines the appropriate tracer dosage. Sampling frequencies depend on the size of the basin—the larger the basin the easier it is to obtain an adequate profile with less frequent sampling is needed. Small basins need more frequent sampling. However, to obtain an adequate profile, large systems may be more difficult to handle than small basins because sampling events are longer in duration thus presenting logistical problems in staffing for sample collection and sample analysis.
- The system conducts the tracer test using either the step-dose or slug-dose methods.
- The system compiles and analyzes the data.
- The system calculates $T_{10.}$

Additional discussions on tracer studies and determining contact times are provided in Appendix D. Additional references for information on tracer studies and details concerning how to conduct one are as follows:

- AWWARF. 1998. “Water Quality Modeling of Distribution System Storage Facilities.” Walter Grayman Consulting Engineer, University of Michigan, SSESCO, Charlotte Smith & Associates, and Blue Ridge Numerics. Denver, CO.

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- TNRCC (Texas Natural Resources Conservation Commission). 1995. *Public Water Supply Technical Guidance Manual*. Austin, TX.

3.3 Monitoring Procedures

This section describes the various monitoring procedures for disinfection profiling as required under the IESWTR. It addresses the following topics: defining disinfection segments within a treatment train based on the number of disinfection application points and determining disinfectant residual concentrations.

3.3.1 Defining Disinfection Segments

The number of disinfection segments within a treatment train must equal or exceed the number of disinfectant application points in the system. For systems with multiple points of disinfectant application, such as ozone followed by chlorine, or chlorine applied at several points in the treatment train, the treatment train should be divided into multiple disinfection segments. Each segment begins at the point of disinfection application and ends at the disinfection residual sampling point. This sampling point is located just prior to the next disinfection application point or, for the last disinfection segment, at or before the entrance to the distribution system or the first customer. As stated before, disinfection segments may include several unit processes of the treatment train.

For instance, if the treatment train includes two applications of chlorine, then the treatment train is divided into two disinfection segments. The first segment begins at the first point of disinfectant application and ends at the residual disinfectant

sampling point, just prior to the second disinfectant application point. The second disinfection segment begins at the second point of disinfectant application and ends at the second disinfectant residual sampling point. For any system, the last disinfection segment must end at or before the entrance to the distribution system or before the first customer. Disinfection segments always start at the application point of a disinfectant and end at the residual sampling point.

Systems may find it useful to divide a single disinfection segment into multiple segments based on different mixing conditions or treatment units. For example, in a direct filtration plant where chlorine is applied at the rapid mixing stage and free chlorine residual is measured at the entrance to the distribution network, the whole plant is a single disinfection segment. The T_{10}/T value multiplied by the free chlorine concentration will give a conservative CT value for the plant (due to free chlorine volatilization at various treatment stages). Therefore, by measuring the free chlorine residual at the end of each treatment unit will provide a different CT value and hence a less conservative estimate of log inactivation.

Section 3.6.1 provides a detailed example of how to define disinfection segments and then use these segments to compute CT and log inactivation values.

3.4 Calculating Estimated Log Inactivation

The objective of this section is to demonstrate, in greater detail, the calculations involved in determining the estimated log inactivations. The section describes the SWTR log inactivation method, procedures to determine minimum regulatory log inactivations for *Giardia* (3-log removal) and viruses (4-log removal), procedures to calculate estimated log inactivations for one disinfection segment of a plant, and the method to determine the overall estimated plant log inactivation.

3.4.1 SWTR Log Inactivation CT Method

The SWTR requires *Giardia* and virus inactivations for drinking water systems. Because of the difficulty in measuring actual microbial inactivations, EPA developed CT tables (see Appendix C) that can be used to estimate the inactivations achieved through chemical disinfection. These tables were developed for approved disinfectants, including chlorine, ozone, chlorine dioxide, and chloramines.

The tables indicate the log inactivation of *Giardia* and viruses corresponding to the operating conditions of temperature, pH, residual disinfectant concentration, and contact time. These tables are presented in the form of log inactivation versus operational conditions since the relationship between CT and log inactivation of *Giardia* is relatively linear for most disinfectant and organism combinations. Log inactivation is an expression of the magnitude of microorganisms that are inactivated during the disinfection process. Table 3-3 presents log inactivations and their corresponding percent inactivations.

Table 3-3. Log Inactivations and Percent Inactivations

Log Inactivation	Percent Inactivation
0.0	0.000
0.5	68.38
1.0	90.00
2.0	99.00
3.0	99.90
4.0	99.99
5.0	99.999
6.0	99.9999
7.0	99.99999

Appendix B provides a detailed explanation for the development of the log inactivation method under the SWTR.

3.4.2 Determining $CT_{3\text{-log, Giardia}}$ and $CT_{4\text{-log, virus}}$

To calculate the estimated log inactivation of a plant, Equation 3-1 and Equation 3-2 must be used to calculate the log inactivations of each disinfection segment. The estimated log inactivations for each segment are then summed to calculate the estimated log inactivations of the plant.

$$\text{Estimated Log Inactivation of Giardia} = 3.0 * \frac{CT_{actua}}{CT_{\mathbf{3}\text{-log, Giardia}}} \quad \textbf{Equation 3-1}$$

$$\text{Estimated Log Inactivation of Viruses} = 4.0 * \frac{CT}{CT_{\mathbf{4}\text{-log, Virus}}} \quad \textbf{Equation 3-2}$$

Equations 3-1 and 3-2 are derived in Section 3.4.3. To use Equation 3-1 and Equation 3-2 in order to calculate the estimated log inactivations of a segment the operator must know the CT_{actual} and the required $CT_{3\text{-log, }Giardia}$ or required $CT_{4\text{-log, virus}}$. CT_{actual} is determined based on daily sampling of the residual disinfectant concentration, C, and calculating the contact time, T_{10}. The sampling, and calculation of contact time, must be performed for each of the disinfectant segments using the procedures described in Section 3.2. This section describes how to determine the required $CT_{3\text{-log, }Giardia}$ and the required $CT_{4\text{-log, virus}}$ for each of the disinfection segments.

Since plants rarely operate at a pH, temperature and residual disinfection concentration that exactly matches the CT tables in the *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources* (AWWA, 1991), the operator may

determine a CT value that lies in between the values. These tables are presented in Appendix C of this guidance manual.

In addition to linear interpolation (see example in Section 3.2.4.1), two methods are presented in this manual for determining the CT values, the "Approximation Method" and the "Regression Method." The PWS should be consistent when choosing a method to calculate CT.

The Regression Method is an efficient way to calculate $CT_{3\text{-log, }Giardia}$ using a computer spreadsheet when free chlorine is the disinfectant being used. This method uses empirical regression equations (Smith et al., 1995) to estimate the CT required to inactivate 3-log *Giardia* with chlorine. An example of the Regression Method is found in Appendix E.

The Approximation Method can be used for $CT_{3\text{-log, }Giardia}$ or $CT_{4\text{-log, virus}}$ for all disinfectants. With this method, conservative values of pH, temperature, and residual disinfectant concentration are used to select a CT value from the table. The Approximation Method is more conservative than linear interpolation and the Regression Method as it approximates the value of the required $CT_{3\text{-log, }Giardia}$ and the required $CT_{4\text{-log, virus}}$. Systems with a pH greater than 9.0 should follow applicable State guidance. The explanation of this method is adapted from a publication by the Texas Natural Resource Conservation Commission (TNRCC, 1998) and is also discussed in the *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources* (AWWA, 1991).

Since it requires no mathematical calculations and reduces errors, the Approximation Method is usually recommended because it is easier to use. However, this method is conservative and slightly underestimates the actual effectiveness of the disinfection process. Also, linear interpolation for all disinfectants is acceptable.

Procedure ($CT_{3\text{-log, Giardia}}$):

- Go to Table 3-4 for *Giardia* inactivation using free chlorine.
- Find the CT for the temperature that is equal to (or slightly below) the actual temperature of the water. For example, if the temperature is 19°C, use the 15°C table.
- Go to the section of the table for the pH which is equal to (or slightly above) the actual pH of the water. For example, if the pH is 7.2, use the pH=7.5 section.
- Look at the far left side of the table and find the chlorine concentration that is equal to (or slightly above) the actual free chlorine concentration. For example, if the chlorine concentration is 1.1 mg/L,

use the 1.2 mg/L row. If the chlorine concentration is above 3mg/L, use the values corresponding to 3mg/L.

- The value shown at the intersection of the concentration row and the temperature/pH column is the value of the required $CT_{3\text{-log, }Giardia}$. For example, at pH 7.5, 15°C, and 1.2 mg/L of chlorine, the required $CT_{3\text{-log, }Giardia}$ is 92 mg-min/L.

Example:

Find the value of $CT_{3\text{-log, }Giardia}$ for a water temperature of 10.8°C, a pH of 8.2, and a residual of 2.5 mg/L for a plant that is using free chlorine as the disinfectant. Use the next lower temperature, 10°C.

Using Table 3-4, look under the pH=8.5 across the 2.6 mg/L row to find that the $CT_{3\text{-log, }Giardia}$ is 234 mg-min/L.

Important Note:

The procedure to calculate the required $CT_{3\text{-log, }Giardia}$ when using free chlorine for water with a pH greater than 9.0 requires the use of the pH 9.0 table or applicable State guidance. No *Giardia* disinfection credit is allowed for free chlorine if the pH in the disinfection segment is above 11.5.

Procedure ($CT_{4\text{-log, virus}}$):

- Go to Table 3-5 for viral inactivation using free chlorine.
- Go to the column for the temperature that is equal to (or slightly below) the actual temperature of the water. For example, if the temperature of the water is 10.5°C, use the temperature = 10°C column.
- The value shown in the 10°C temperature column is the value of $CT_{4\text{-log, virus}}$.

Table 3-4. Required CT Values (mg-min/L) for 3-log Inactivation of *Giardia* Cysts by Free Chlorine, pH 6.0-9.0

Chlorine Concentration (mg/L)	Temperature<5°C							Temperature=5°C							Temperature=10°C						
	pH							pH							pH						
	<=6.0	6.5	7.0	7.5	8.0	8.5	9.0	<=6.0	6.5	7.0	7.5	8.0	8.5	9.0	<=6.0	6.5	7.0	7.5	8.0	8.5	9.0
<=0.4	137	163	19	23	277	329	390	97	11	13	166	198	236	279	73	88	104	12	149	177	209
0.6	141	169	20	23	286	342	407	100	12	14	171	204	244	291	75	90	107	12	153	183	218
0.8	145	172	20	24	295	354	422	103	12	14	175	210	252	301	78	92	110	13	158	189	226
1	148	176	21	25	304	365	437	105	12	14	179	216	260	312	79	94	112	13	162	195	234
1.2	152	180	21	25	313	376	451	107	12	15	183	221	267	320	80	95	114	13	166	200	240
1.4	155	184	22	26	321	387	464	109	13	15	187	227	274	329	82	98	116	14	170	206	247
1.6	157	189	22	27	329	397	477	111	13	15	192	232	281	337	83	99	119	14	174	211	253
1.8	162	193	23	27	338	407	489	114	13	16	196	238	287	345	86	10	122	14	179	215	259
2	165	197	23	28	346	417	500	116	13	16	200	243	294	353	87	10	124	15	182	221	265
2.2	169	201	24	29	353	426	511	118	14	16	204	248	300	361	89	10	127	15	186	225	271
2.4	172	205	24	29	361	435	522	120	14	17	209	253	306	368	90	10	129	15	190	230	276
2.6	175	209	25	30	368	444	533	122	14	17	213	258	312	375	92	11	131	16	194	234	281
2.8	178	213	25	31	375	452	543	124	14	17	217	263	318	382	93	11	134	16	197	239	287
3	181	217	26	31	382	460	552	126	15	18	221	268	324	389	95	11	137	16	201	243	292

Chlorine Concentration (mg/L)	Temperature=15°C							Temperature=20°C							Temperature=25°C						
	pH							pH							pH						
	<=6.0	6.5	7.0	7.	8.0	8.5	9.0	<=6.	6.5	7.0	7.5	8.0	8.5	9.0	<=6.0	6.5	7.0	7.5	8.0	8.5	9.0
<=0.4	49	59	70	83	99	118	140	36	44	52	62	74	89	105	24	29	35	42	50	59	70
0.6	50	60	72	86	102	122	146	38	45	54	64	77	92	109	25	30	36	43	51	61	73
0.8	52	61	73	88	105	126	151	39	46	55	66	79	95	113	26	31	37	44	53	63	75
1	53	63	75	90	108	130	156	39	47	56	67	81	98	117	26	31	37	45	54	65	78
1.2	54	64	76	92	111	134	160	40	48	57	69	83	100	120	27	32	38	46	55	67	80
1.4	55	65	78	94	114	137	165	41	49	58	70	85	103	123	27	33	39	47	57	69	82
1.6	56	66	79	96	116	141	169	42	50	59	72	87	105	126	28	33	40	48	58	70	84
1.8	57	68	81	98	119	144	173	43	51	61	74	89	108	129	29	34	41	49	60	72	86
2	58	69	83	10	122	147	177	44	52	62	75	91	110	132	29	35	41	50	61	74	89
2.2	59	70	85	10	124	150	181	44	53	63	77	93	113	135	30	35	42	51	62	75	90
2.4	60	72	86	10	127	153	184	45	54	65	78	95	115	139	30	36	43	52	63	77	92
2.6	61	73	88	10	129	156	188	46	55	66	80	97	117	141	31	37	44	53	65	78	94
2.8	62	74	89	10	132	159	191	47	56	67	81	99	119	143	31	37	45	54	66	80	96
3	63	76	91	11	134	162	195	47	57	68	83	101	122	146	32	38	46	55	67	81	97

For CT values for the inactivation of *Giardia* and viruses using chlorine dioxide, ozone, or chloramines, use the Tables in Appendix C.

Example:

Find the value of the required $CT_{4\text{-log, virus}}$ for a water temperature of 10.8°C and a pH of 9.0 for a plant that is using free chlorine as the disinfectant.

Using Table 3-5 for free chlorine and using 10°C, the required $CT_{4\text{-log, virus}}$ is 6 mg-min/L.

Table 3-5. Required CT Values (mg-min/L) for 4-Log Inactivation of Viruses by Free Chlorine, pH 6.0-9.0

Temperature (°C)	CT Value (mg-min/L)	Temperature (°C)	CT Value (mg-min/L)
0.5	12	13	4.8
1	11.6	14	4.4
2	10.7	15	4
3	9.8	16	3.8
4	8.9	17	3.6
5	8	18	3.4
6	7.6	19	3.2
7	7.2	20	3
8	6.8	21	2.8
9	6.4	22	2.6
10	6	23	2.4
11	5.6	24	2.2
12	5.2	25	2

3.4.3 Log Inactivation Calculations

This section provides the procedures for calculating log inactivations for generating disinfection profiles. This section provides an example of calculating estimated log inactivations using the Approximation Method to determine $CT_{3\text{-log, }\textit{Giardia}}$ and $CT_{4\text{-log, virus}}$ when using free chlorine at pH less than or equal to 9.0. At pH greater than 9.0, systems must use the pH 9.0 table or State-approved protocol. The procedure is as follows:

Estimated log inactivation is calculated by assuming the relationship between CT and log inactivation is linear and can be represented mathematically by the following equation:

$$\frac{\text{Estimated Log Inactivation}}{\text{3 - Log Inactivation}} = \frac{CT_{actual}}{CT_{99.9\ (\text{or 3-log, } Giardia)}}$$

Rearranging the equation:

$$\text{Estimated Log Inactivation} = 3.0 * \frac{CT_{actual}}{CT_{required}}$$

Assuming a base condition of 3-log inactivation for *Giardia* and 4-log inactivation for viruses, the general equations are as follows:

$$\text{Estimated Log Inactivation of Giardia} = 3.0 * \frac{CT_{actual}}{CT_{\mathbf{3}\text{-log, Giardia}}} \qquad \textbf{Equation 3-1}$$

$$\text{Estimated Log Inactivation of Viruses} = 4.0 * \frac{CT_{actual}}{CT_{\mathbf{4}\text{-log, Virus}}} \qquad \textbf{Equation 3-2}$$

These general equations are actually extrapolations of the SWTR based on the 3-log and 4-log inactivation values. However, they can be used by any surface water treatment plant, whether practicing filtration or not. The equations remain valid for systems with lower required inactivations (i.e., filtration plants) because of the linear relationship between CT and log inactivation.

3.4.4 Summing the Estimated Log Inactivations of each Segment to Determine the Log Inactivation of the Plant

Once the $CT_{3\text{-log, }Giardia}$ and $CT_{4\text{-log, virus}}$ have been determined for a segment in a treatment plant, this information can be used in Equation 3-1 or Equation 3-2 along with the CT_{actual} to calculate the daily log inactivation of *Giardia* or viruses for a given segment. The daily log inactivation of the plant is then calculated by summing the log inactivations of the individual segments into a daily log inactivation for the plant as follows:

$$\text{Total plant log inactivation} = \Sigma(\text{segment log inactivation})$$

3.5 The Completed Profile

The disinfection profile consists of the daily log *Giardia* (or virus) inactivation levels plotted against time. The log inactivation calculation methodology was used for a specific system as an example for developing the IESWTR. Figures 3-2 through 3-4 present the disinfection profiles showing variations in daily log inactivations of *Giardia* at a sample facility from 1994 through 1996. In general, as can be seen from Figures 3-2 and 3-3, seasonal variations in log removal of *Giardia* can be discerned from the disinfection profiles. However, as depicted in Figure 3-4, variations to the expected seasonal disinfection profile pattern may occur in a year with atypical weather conditions. Based on

the three years of data, it appears that the lowest inactivation level at this facility occurred at the end of June 1995.

Systems should keep the completed profile and supporting data on file at the treatment plant or at its offices in graphical form, as a spreadsheet, or in some other format approved by the State. A system is not required to submit the profile and supporting data to the State unless it is requested or if the system intends to make a significant modification to its disinfection practice. It is important to retain the profile and supporting data in the event the system decides to modify its disinfection practice and must therefore, create a benchmark.

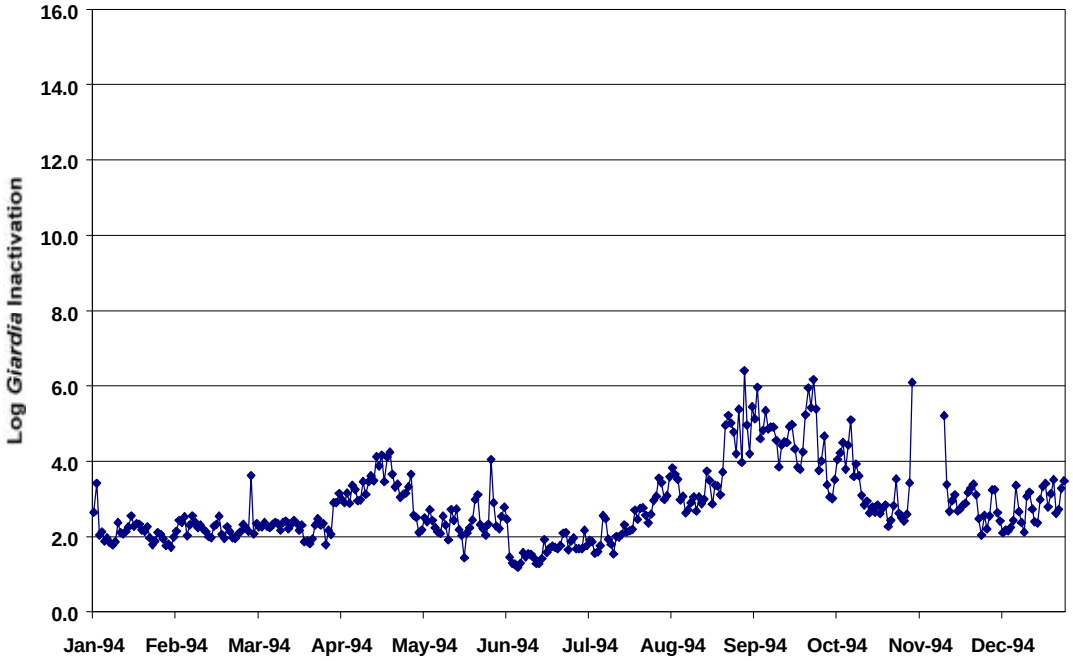

Figure 3-2. 1994 Profiling Data

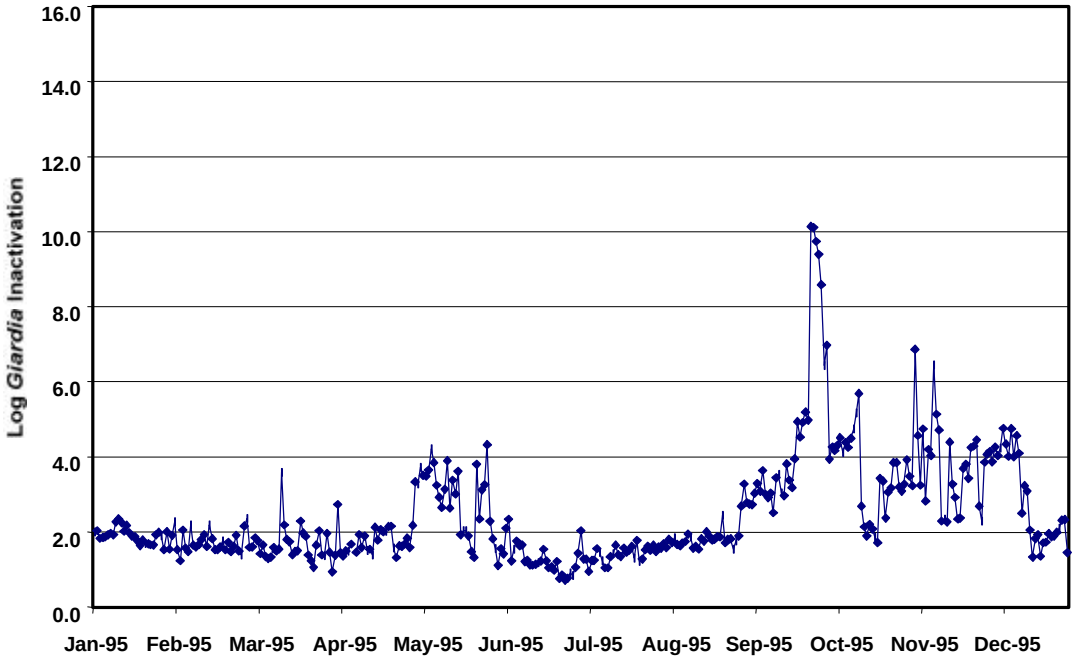

Figure 3-3. 1995 Profiling Data

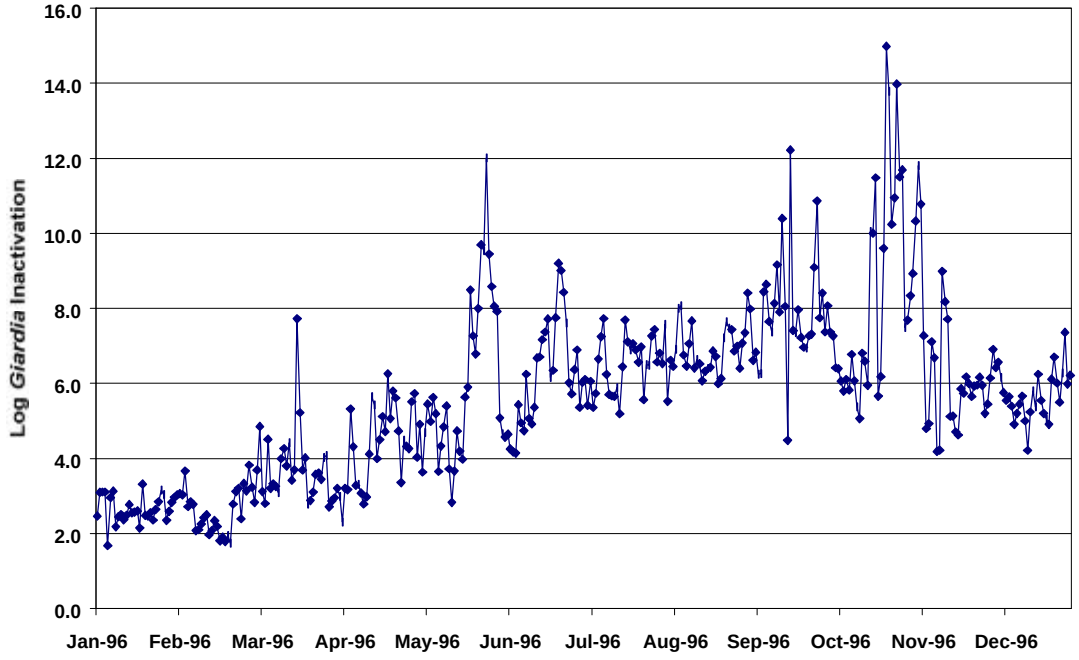

Figure 3-4. 1996 Profiling Data

3.6 Examples of Estimating Log Inactivation of Giardia and Viruses for Conventional Filtration Plants

These examples are intended to enhance the discussion of CT calculations provided earlier. These examples illustrate the necessary information and computations needed to perform a complete CT analysis and to determine log inactivation of *Giardia* and viruses for a single day. Where applicable, a reference is given to the location within the text where a more complete description of the topic can be found. Chapter 4 continues these examples by developing a disinfection benchmark. Chapter 5 also demonstrates the utility of a disinfection benchmark in designing alternative disinfection strategies to control DBPs while meeting existing levels of disinfection.

The data required for estimating log inactivation are:

- pH (chlorine only)
- Water temperature, in °C
- Disinfectant residual, in mg/L
- Peak hourly rate for the day, in gpm
- Volume of water in each segment of treatment plant, in gallons
- Baffling conditions.

The last two data elements, the volume of water in each segment and the baffling conditions, are set by the treatment plant configuration. pH and water temperature measurements should be measured at the same time the disinfectant residual sample is being taken. Measurements of these parameters should be conducted during or about the peak hour demand time.

As stated earlier, when calculating estimated log inactivation the following rules are set as guidance to develop a conservative (when compared to direct linear interpolation of CT values) log inactivation estimate:

1. Temperature – if the water temperature falls in between what is listed in the tables the system should use the CT value corresponding to the next lower temperature.

2. pH – if the water pH falls in between what is listed in the tables, systems should use the CT value corresponding to the next higher pH value. For pH values greater than 9.0, systems should use pH 9.0 or apply State guidance.

3. Disinfectant residual – if the disinfectant residual value is in between what is listed in the tables, the system should use the next higher value to calculate the $CT_{3\text{-log, }\textit{Giardia}}$. If the disinfectant residual is greater than 3 mg/L, the system must use 3 mg/L for calculating estimated CT and to determine the $CT_{3\text{-log, }\textit{Giardia}}$ value and for calculation of CT_{actual}.

3.6.1 Example of Developing a Disinfection Profile for a 40 mgd Plant

This example considers disinfection at a 40 mgd conventional filtration plant. The plant is five years old and is expected to reach capacity in 25 years. A process diagram for the plant is shown in Figure 3-5. The plant process train is divided into three disinfection segments. Chlorine is dosed at two locations: to the raw water and immediately prior to filtration. Ammonia is applied just prior to the clearwell to form chloramines. The three disinfection segments are shown at the top of the diagram. Each segment begins at the point of disinfectant application, and ends at the disinfectant residual sampling point. The diagram indicates information needed to calculate the theoretical detention time using the peak hourly flow rate and T_{10} for each unit process determined by the baffling factor approach discussed earlier and in Appendix D.

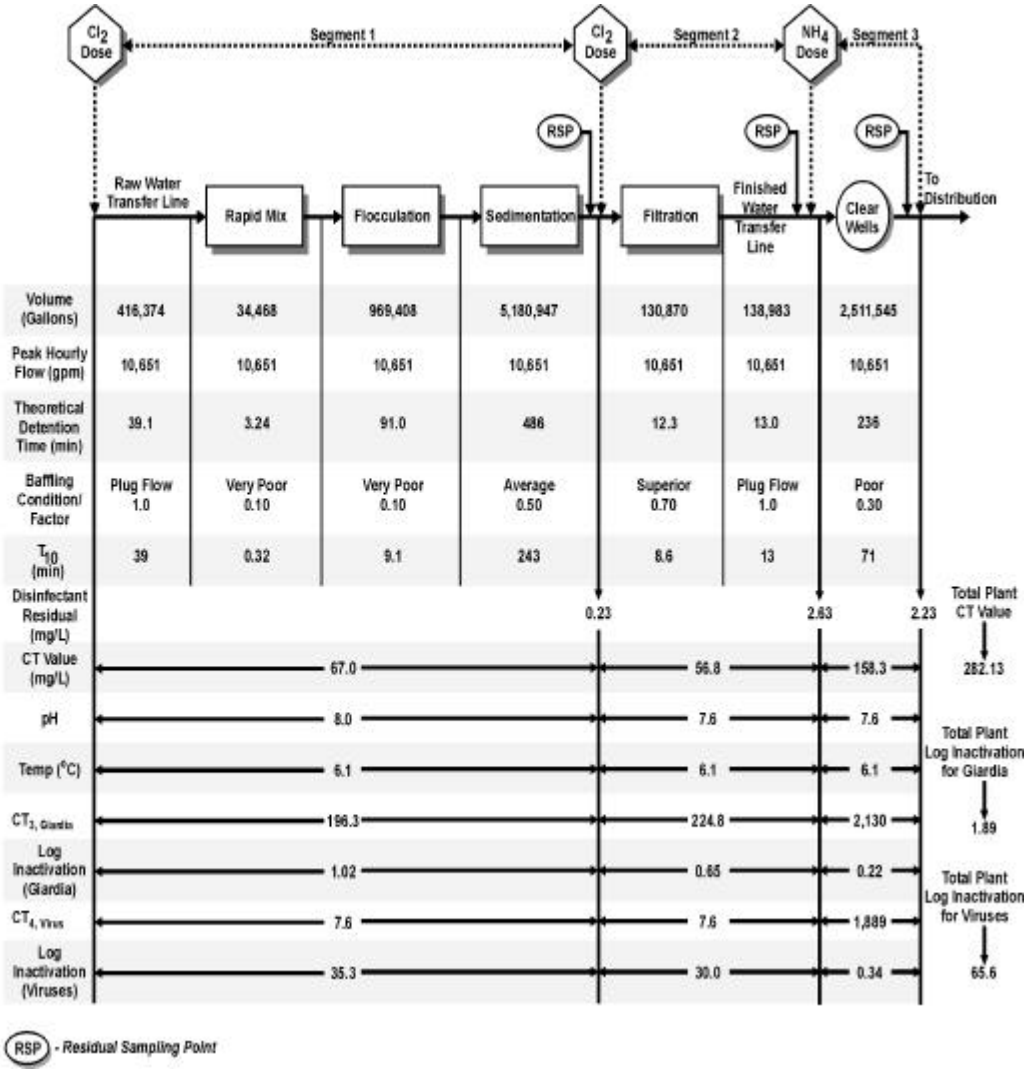

Figure 3-5. 40 mgd Conventional Filtration Process Diagram

The plant actually consists of four identical, parallel 10 mgd process trains, so there are four rapid mix basins, four flocculation basins, etc., all of equivalent size. Because each of the four trains are identical, the approach to calculating the TDT for a process (e.g., rapid mix) is to sum the volumes of the reactors (four times the volume of a single reactor) and divide by the total plant peak hourly flow rate. Table 3-6 summarizes the design conditions for each unit process.

Table 3-6. Unit Process Design Conditions Summary

	Raw Water Line	Rapid Mix	Flocculation	Sedimentation	Filtration	Finished Water Transfer Line	Clearwells
Design Flow (mgd)	40	40	40	40	40	40	**40**
Theoretical Detention Time (min)	15.0	1.24	34.9	372	4.71	5.00	**90.4**
Hydraulic Loading Rate	*n/a*	*n/a*	*n/a*	0.362 *gpm/ft²*	4.8 *gpm/ft²*	*n/a*	***n/a***

Note: See Figure 3-5 for reactor volumes.
n/a – not applicable

The design parameters listed in Table 3-6 are higher than current plant peak water demand. Moreover, treatment plant peak hourly flow rate varies by day of the week, by season, by special events, and by type of economic activities and cycles which may require heavy uses of water during specific times of the day.

The calculations detailed in Section 3.6.1.1 use the data presented in Figure 3-5. These calculations illustrate the procedure for computing the log inactivations of *Giardia* and viruses. The first step involves collecting the appropriate data required for computing log inactivation. Since chlorine is used in this plant, pH and temperature are measured at the same times and locations as the chlorine residual (i.e., the residual sampling points). Temperature measured at the head of the plant is acceptable because it is generally lower than the temperature of the finished water. For this plant, the peak hourly flow rate during the day of interest was determined to be 10,651 gallons per minute (15.3 mgd). This flow is determined by examining the flow record to find the greatest volume of water passing through the system during any one hour during the day. The peak hourly rate, during the day of interest, is about 38 percent of plant capacity. This low percentage level is expected to occur on a low-demand day and in a five-year-old plant that is expected to reach capacity in 25 years.

For each unit process within a disinfection segment, the volume, theoretical detention time, baffling condition, and T_{10} must be determined if tracer study data are not available. Volume calculations for each unit process are presented later Section 3.6.1.1, and are discussed in Appendix D. The volume of the unit occupied by water, not the total unit

volume, is used to compute TDT. For example, for filters, the volume of media must be subtracted to get the volume of the filter process occupied by water. Additionally, for clearwells or tanks with variable storage volume, the minimum storage volume during the day is used. The different types of equations used to calculate the volumes are shown in Table 3-7.

Table 3-7. Volume Equations

Volume of Filtration	= Volume of Filters – Volume of Media = (# of filters) x (Length) x (Width) x (Total depth) – (# of filters) x (Length) x (Width) x (Depth of media) x (Porosity)
Volume of Raw Water Pipe	= (Length) x (Cross-sectional Area)
Volume of Rapid Mix Basins	= (# of basins) x (Length) x (Width) x (Depth of water)
Volume of Water in Clearwells	= (# of tanks) x (Minimum water depth) x (Cross-sectional Area)

The theoretical detention time is the unit process volume divided by the peak hourly flow rate. This theoretical detention time must be multiplied by a baffling factor to yield T_{10} (i.e., contact time), if tracer study data are not available. Baffling classifications, T_{10} definition, and determination are discussed in detail in Appendix D.

3.6.1.1 Contact Time Computations for 40 mgd Plant

The following pages illustrate detailed calculations to determine contact time for each unit process, as shown in Figure 3-5.

Unit Process: RAW WATER PIPE

VOLUME OF RAW WATER PIPE = *(Length) x (Cross-sectional Area)*

= $(2{,}835\ ft) \times p \times (2.5\ ft)^2$

= $55{,}665\ ft^3$

Convert cubic feet to gallons = $55{,}665\ ft^3 \times \frac{7.48 gallons}{1 ft^3} = 416{,}374\ gallons$

FLOW RATE = Peak hourly flow occurring during the 24-hour period

= 10,651 gpm

THEORETICAL DETENTION TIME (TDT)= $\frac{\text{Volume of Unit Process}}{\text{Flow Rate}}$

TDT RAW WATER PIPE = $\frac{416{,}374\ \text{gallons}}{10{,}651 \text{gpm}}$

= *39.1 minutes*

BAFFLING CONDITION = Perfect flow (Refer to Appendix D for determining baffling factors).

T_{10}/T = *1.0*

Unit T_{10} RAW WATER PIPE = $TDT \times T_{10}/T$

= *(39.1 minutes) x (1.0)*

= *39 minutes*

Unit Process: RAPID MIX BASIN

VOLUME OF RAPID MIX BASINS = *(# of basins) x (Length) x (Width) x (Depth of Water)*

= *(4) x(12 ft) x (12 ft) x (8 ft)*

= *4,608 ft^3*

Convert cubic feet to gallons = $4{,}608\ ft^3 \times \frac{7.48 gallons}{1 ft^3} = 34{,}468\ gallons$

FLOW RATE = Peak hourly flow occurring during the 24-hour period

= 10,651 gpm

THEORETICAL DETENTION TIME (TDT) = $\frac{\text{Volume of Unit Process}}{\text{Flow Rate}}$

TDT RAPID MIX BASINS = $\frac{34{,}468\ \text{gallons}}{10{,}651\ \text{gpm}}$

= *3.24 minutes*

BAFFLING CONDITION = Unbaffled basin (Refer to Appendix D for determining baffling factors).

T_{10}/T = 0.10

Unit T_{10} RAPID MIX BASINS = $TDT \times T_{10}/T$

= *(3.24 minutes) x (0.10)*

= *0.32 minutes*

Unit Process: FLOCCULATION

VOLUME OF FLOCCULATION BASINS = *(# of basins) x (Length) x (Width) x (Depth of Water)*

= *(4) x (60 ft) x (30 ft) x (18 ft)*

= *129,600 ft^3*

Convert cubic feet to gallons = $129{,}600\ ft^3 \times \frac{7.48 gallons}{1 ft^3} = 969{,}408\ gallons$

FLOW RATE = Peak hourly flow occurring during the 24-hour period

= 10,651 gpm

THEORETICAL DETENTION TIME (TDT) = $\frac{\text{Volume of Unit Process}}{\text{Flow Rate}}$

TDT FLOCCULATION BASIN = $\frac{969{,}408\ \text{gallons}}{10{,}651\ \text{gpm}}$

= *91.0 minutes*

BAFFLING CONDITION = Unbaffled basin (Refer to Appendix D for determining baffling factors).

T_{10}/T **=** 0.10

Unit T_{10} FLOCCULATION BASIN = $TDT \times T_{10}/T$

= *(91.0 minutes) x (0.10)*

= *9.1 minutes*

Unit Process: SEDIMENTATION

VOLUME OF SEDIMENTATION BASINS = *(# of basins) x (Length) x (Width) x (Depth of Water)*

= *4 x 234 ft x 74 ft x 10 ft*

= *692,640 ft^3*

Convert cubic feet to gallons = $692{,}640\ ft^3 \times \frac{7.48 gallons}{1 ft^3} = 5{,}180{,}947\ gallons$

FLOW RATE = Peak hourly flow occurring during the 24-hour period

= 10,651 gpm

THEORETICAL DETENTION TIME (TDT) = $\frac{\text{Volume of Unit Process}}{\text{Flow Rate}}$

TDT SEDIMENTATION BASIN = $\frac{5{,}180{,}947 \text{ gallons}}{10{,}651 \text{ gpm}}$

= *486 minutes*

BAFFLING CONDITION = Average baffling conditions (Refer to Appendix D for determining baffling factors).

T_{10}/T **=** 0.50

Unit T_{10} SEDIMENTATION BASINS = $TDT \times T_{10}/T$

= *(486 minutes) x (0.50)*

= *243 minutes*

Unit Process: FILTRATION

VOLUME OF FILTRATION = Volume of Filters – Volume of Media

= *(# of filters) x (Length) x (Width) x (Total Depth)**

(# of filters) x (Length) x (Width) x (Depth of Media) x (Porosity)

= *(9) x (36 ft) x (18 ft) x (4 ft) – (9) x (36 ft) x (18 ft) x (2 ft) x (0.5)*

= *23,328 ft^3 - 5,832 ft^3 = 17,496 ft^3*

*Total depth is the depth of media plus the minimum depth of water above the media. For this example, the plant operates with 2 feet of media and a minimum of 2 feet of water above the media.

Convert cubic feet to gallons = $17{,}496\ ft^3 \times \frac{7.48 gallons}{1 ft^3} = 130{,}870 \text{ gallons}$

FLOW RATE = Peak hourly flow occurring during the 24-hour period

= 10,651 gpm

THEORETICAL DETENTION TIME (TDT) = $\frac{\text{Volume of Unit Process}}{\text{Flow Rate}}$

TDT FILTRATION BASIN = $\frac{130{,}870 \text{ gallons}}{10{,}651 \text{ gpm}}$

= *12.3 minutes*

BAFFLING CONDITION = Superior baffling conditions (Refer to Appendix D for determining baffling factors).

T_{10}/T = 0.70

Unit T_{10} FILTRATION = $TDT \times T_{10}/T$

= *(12.3 minutes) x (0.70)*

= *8.6 minutes*

Unit Process: FINISHED WATER PIPE

VOLUME OF FINISHED WATER PIPE = *(Length) x (Cross-Sectional Area)*

= *946.3 ft x p x (2.5 f)t^2*

= *18,581 ft^3*

Convert cubic feet to gallons = $18{,}581\ ft^3 \times \frac{7.48 gallons}{1 ft^3} = 138{,}983\ gallons$

FLOW RATE = Peak hourly flow occurring during the 24-hour period

= *10,651 gpm*

THEORETICAL DETENTION TIME (TDT) = $\frac{\text{Volume of Unit Process}}{\text{Flow Rate}}$

TDT FINISHED WATER PIPE = $\frac{138{,}983 \text{ gallons}}{10{,}651 \text{gpm}}$

= *13.0 minutes*

BAFFLING CONDITION = Plug flow baffling conditions (Refer to Appendix D for determining baffling factors).

T_{10}/T = 1.0

Unit T_{10} FINISHED WATER LINE = $TDT \times T_{10}/T$

= *(13.0 minutes) x (1.0)*

= *13 minutes*

Unit Process: CLEARWELLS

VOLUME OF WATER IN CLEARWELLS* = *(# of tanks) x (Minimum water depth) x (Cross-sectional Area)*

= *(2) x (20 ft) x (8,394.2 ft)*

= $335{,}768\ ft^3$

Convert cubic feet to gallons = $335{,}768\ ft^3 \times \frac{7.48 gallons}{1 ft^3} = 2{,}511{,}545\ gallons$

*Volume of clearwells should reflect a constant minimum storage level that is maintained during peak hour flows. See Chapter 3 and Appendix D for more discussion.

FLOW RATE = Peak hourly flow occurring during the 24-hour period

= 10,651 gpm

THEORETICAL DETENTION TIME (TDT) = $\frac{\text{Volume of Unit Process}}{\text{Flow Rate}}$

TDT CLEARWELLS = $\frac{2{,}511{,}545 \text{ gallons}}{10{,}651 \text{ gpm}}$

= *236 minutes*

BAFFLING CONDITION = Poor baffling conditions (Refer to Appendix D for determining baffling factors).

T_{10}/T = 0.30

Unit T_{10} CLEARWELLS = $TDT \times T_{10}/T$

= *(236 minutes) x (0.30)*

= *71 minutes*

3.6.1.2 Log Inactivation Computations for 40 mgd Plant

Following the diagram in Figure 3-5, the next step is to compute the estimated log inactivation of *Giardia* and viruses for each disinfection segment. ***Note that profiling and benchmarking based on virus inactivation is required only for systems proposing to add or switch to ozone or chloramines. Profiling and benchmarking for virus inactivation is strongly recommended for systems proposing to add or switch to chlorine dioxide.*** This step requires the temperature, pH (only for chlorine), and residual disinfectant concentration for each segment, as well as the T_{10} values computed in Section

3.6.1.1. The segment T_{10} is the sum of the T_{10} for each unit process in the segment. To compute CT_{actual}, multiply the segment T_{10} by the residual disinfectant concentration.

Look up the CT required to inactivate 3-log *Giardia* ($CT_{3\text{-log, }Giardia}$) and 4-log viruses ($CT_{4\text{-log, virus}}$) in the CT tables (Tables 3-4 and 3-5 or Appendix C). If the temperature, pH, or residual concentration values fall between those values listed in Tables 3-4 and 3-5 use the guidelines stated earlier in Section 3.6. Once CT_{actual} and the CT required for 3-log *Giardia* and 4-log virus inactivation are calculated, the estimated log inactivation for the segment can then be computed:

$$\text{Estimated Segment log inactivation of } Giardia = 3.0 * CT_{actual} / CT_{3\text{-log, }Giardia}$$

$$\text{Estimated Segment log inactivation of Viruses} = 4.0 * CT_{actual} / CT_{4\text{-log, virus}}$$

Determine log inactivation for each disinfection segment for the 40 mgd plant example:

SEGMENT 1

The concentration of chlorine measured at the end of Segment 1 was 0.23 mg/L.

CT_{actual} = (residual disinfection concentration) x (sum of T_{10}'s for each unit process)

= (0.23 mg/L of chlorine) x (39 + 0.32 + 9.1 + 243 minutes)

= 67.03 mg-min/L

Determine the $CT_{3\text{-log, }Giardia}$ (i.e., 3-log inactivation of *Giardia*) from Table 3-4 or the CT tables in Appendix C using the appropriate temperature, pH, and residual chlorine concentration. Assuming:

Temperature = $6.1^{o}C$

pH = 8.0

Cl_2 = 0.23 mg/L

Using Table 3-4 for 5°C, pH 8.0, and concentration = 0.4 mg/L to select the appropriate CT value.

$$CT_{3\text{-log, }Giardia} = 198 \text{ mg-min/L}$$

Determine the $CT_{4\text{-log, virus}}$ (i.e., 4-log inactivation of viruses) from Table 3-5 or the CT tables in Appendix C.

Temperature = 6.1°C

pH = 8.0

Cl_2 = 0.23mg/L

Since the temperature of 6.1°C is not covered in the CT table, use the next lower temperature, 6°C.

$CT_{4\text{-log, virus}}$ = 7.6 mg-min/L

Determine estimated log inactivation of *Giardia* and viruses for Segment 1:

Estimated Log inactivation of *Giardia* = 3.0 x (CT_{actual} / $CT_{3\text{-log, }Giardia}$)

= 3.0 x (67.03 / 198)

= 1.02

Estimated Log inactivation of viruses = 4.0 x (CT_{actual} / $CT_{4\text{-log, virus}}$)

= 4.0 x (67.03 / 7.6)

= 35.3

SEGMENT 2

The concentration of chlorine measured at the end of Segment 2 was 2.63 mg/L.

CT_{actual} = (residual disinfection concentration) x (sum of T_{10}'s for each unit process)

= (2.63 mg/L of chlorine) x (8.6 minutes + 13.0 minutes)

= 56.8 mg-min/L

Determine $CT_{3\text{-log, }Giardia}$ (i.e., 3-log inactivation of *Giardia*) from Table 3-4 using temperature, pH, and residual chlorine concentration. Assuming:

Temperature = 6.1°C

pH = 7.6

Cl_2 = 2.63 mg/L

$CT_{3\text{-log, }Giardia}$= 263 mg-min/L

Determine required $CT_{4\text{-log, virus}}$ (i.e., 4-log inactivation of viruses) from Table 3-5 or the CT tables in Appendix C using the following temperature and pH.

Temperature = 6.1°C

pH = 7.6

Since the temperature of 6.1°C is not covered in Table 3-5, use the next lower temperature.

$CT_{4\text{-log, virus}}$ = 7.6 mg-min/L

Determine log inactivation of *Giardia* and viruses for Segment 2:

Estimated Log inactivation of *Giardia*= 3.0 x (CT_{actual} / $CT_{3\text{-log, }Giardia}$)

= 3.0 x (56.8 / 263)

= 0.65

Estimated Log inactivation of viruses = 4.0 x (CT_{actual} / $CT_{4\text{-log, virus}}$)

= 4.0 x (56.8 / 7.6)

= 30.0

SEGMENT 3

The concentration of chloramine measured at the end of Segment 3 was 2.23 mg/L.

CT_{actual} = (residual disinfection concentration) x (sum of T_{10}'s for each unit process)

= (2.23 mg/L of chloramine) x (71 minutes)

= 158.3 mg-min/L

Determine $CT_{3\text{-log, }Giardia}$ (i.e., 3-log inactivation of *Giardia*) from the chloramine tables in Appendix C. Assuming:

Temperature = 6.1 °C

Since the temperature of 6.1°C is not covered in the Appendix C CT tables for chloramine, use the next lower temperature.

$CT_{3\text{-log, }Giardia}$ = 2,130 mg-min/L

Determine $CT_{4\text{-log, virus}}$ (i.e., 4-log inactivation of viruses) from the CT tables in Appendix C using temperature. Assuming:

Temperature = 6.1 °C

Since the temperature of 6.1 ^{o}C is not covered in the CT tables, use the next lower temperature.

$$CT_{4\text{-log, virus}} = 1{,}889 \text{ mg-min/L}$$

Determine estimated log inactivation of *Giardia* and viruses for Segment 3:

$$\text{Estimated Log inactivation of } \textit{Giardia} = 3.0 * (CT_{actual} / CT_{3\text{-log, } \textit{Giardia}})$$

$$= 3.0 * (158.3 / 2{,}130)$$

$$= 0.22$$

$$\text{Estimated Log inactivation of viruses} = 4.0 * (CT_{actual} / CT_{4\text{-log, virus}})$$

$$= 4.0 * (158.3 / 1{,}889)$$

$$= 0.34$$

3.6.1.3 Estimated Plant Log Inactivation for 40 mgd Plant

The final step is to calculate the estimated log inactivation by chemical disinfection for the entire plant. The estimated plant log inactivation is simply the sum of the segment log inactivation for the particular organism (*Giardia* or viruses).

Estimated Log inactivation for the entire plant by disinfection chemical	=	Sum of estimated log inactivations of each disinfection segment
	=	Estimated Log inactivation Segment 1 + Estimated Log inactivation Segment 2 + Estimated Log inactivation Segment 3
Estimated Log inactivation of *Giardia* for the entire plant	=	1.02 + 0.65 + 0.22
	=	1.89
Estimated Log inactivation of viruses for the entire plant	=	35.3 + 30.0 + 0.34
	=	65.64

EPA guidance suggests that conventional filtration treatment receive a 2.5-log credit for *Giardia* removal through sedimentation and filtration. Therefore, to comply with the SWTR, the plant must achieve at least 0.5-logs inactivation (to achieve at least 3.0-logs of combined removal and inactivation). This plant is in compliance with the SWTR.

3.6.2 Example of Developing a Disinfection Profile for a 5 mgd Plant for One Month

This disinfection profile example was developed for a direct filtration treatment plant in Missouri with a design capacity of 5 mgd. The treatment plant consists of an intake structure with a pumping station, two units for rapid mixing, two flocculation units, and three sand filters of equal treatment capacity. Each sand filter is sized for situatuins when one is out of service, the other two are capable of carrying design flow. The treatment plant has a clearwell that is used as a contact basin and is used for storage. The volume of the clear well is equivalent to one-day average production (2.5 million gallons); the dead storage volume is 1.25 million gallons (storage volume used to calculate contact time).

Table 3-8 presents the output data of a spreadsheet designed to develop a disinfection profile for systems using various chemical disinfectants. Because chlorine is applied at the rapid mixing stage and the free chlorine residual is measured only at the clearwell, the same value is used for various treatment units.

The data presented in Table 3-8 for pH, temperature and chlorine residual values are actual readings from the treatment plant. The plant is expected to run at design capacity in 15 years. Currently it serves a population of about 12,000 and runs a maximum peak hourly rate of 2000 gpm or 2.6 mgd.

The input data needed to calculate daily log inactivation and develop disinfection profile are: the type of disinfectant, date, daily pH, temperature, peak hourly rate, volume of each treatment process and disinfectant free residual at each sampling point. Table 3-9 presents the input and output data used for 9/01/96. Using a spreadsheet, Table 3-9 is developed as an example of automated calculations of estimated log inactivation for *Giardia* and viruses using the Approximation Method for the month of September 1996.

Details on how to calculate volume of water in each process unit were provided previously in a step-by-step detailed example of a 40-mgd treatment plant in Section 3.6.1.

Table 3-8. Actual Readings From a SW Treatment Plant in Missouri

	SEGMENT 1				
Date	**09/01/96**				
Disinfectants	**Cl_2**				
Process Name	**Rapid Mix**	**Flocculation**	**Sedimentation**	**Filtration**	**Clear Well**
Volume (gal)	**3,500**	**130,000**	**0**	**80,000**	**1,250,000**
Baffling Condition (T_{10}/T)	**0.1**	**0.3**	**0.1**	**0.3**	**0.1**
Peak Hourly Flow (gpm)	1,820	1,820	1,820	1,820	1,820
Theoretical Detention Time (min)	1.92	71.43	0.00	43.96	686.81
T_{10} (min)	0.19	21.43	0.00	13.19	68.68
Free Disinfectant Concentration (mg/L)[1]	0.95	0.95	0.95	0.95	0.95
Plant CT Value (mg-min/L)	0.18	20.36	0.00	12.53	65.25
pH	7.59	7.59	7.59	7.59	7.59
Temperature (°C)	23.9	23.9	23.9	23.9	23.9
$CT_{3\text{-log,Giardia}}$	81	81	81	81	81
$CT_{4\text{-log,vruses}}$	2.4	2.4	2.4	2.4	2.4
Estimated Plant Giardia Log Inactivation	0.01	0.75	0.00	0.46	2.42
Estimated Plant Viruses Log Inactivation	0.30	33.93	0.00	20.88	108.75

Segment 1 Totals

T_{10}	103.49
CT	98.31
$CT_{3\text{-log,Giardia}}$	81
$CT_{4\text{-log,vruses}}$	2.4
Giardia Log Inactivation	**3.64**
Virus Log Inactivation	**163.86**

[1] Plant only measures residual at discharge from clearwell, therefore, this residual is assumed to be the residual throughout the plant.

Table 3-9. Input and Output Data Used to Calculate Log Inactivations

		SEGMENT 1							
Date	**Peak Hourly Flow Rate (gpm)**	**pH**	**Temperature**	**Disinfectant Residual (mg/L)**	**Segment CT Actual**	**3-log *Giardia* CT**	**4-log Viruses CT**	**Estimated Segment *Giardia* Inactivation[1]**	**Estimated Segment Virus Inactivation[2]**
09/01/96	1,820	7.59	23.9	0.95	98.31	81	2.4	3.64	163.86
09/02/96	1,880	7.85	22.8	1.17	117.22	83	2.6	4.24	180.34
09/03/96	1,855	7.87	21.5	1.02	103.57	83	2.8	3.74	147.95
09/04/96	1,840	7.81	21	1.23	125.91	85	2.8	4.44	179.87
09/05/96	1,840	7.86	21	1.03	105.44	83	2.8	3.81	150.62
09/06/96	1,830	7.94	20.3	1.04	107.04	83	3.0	3.87	142.72
09/07/96	1,810	8.11	19.4	1.1	114.47	134	3.2	2.56	143.08
09/08/96	1,820	7.89	18.9	1.03	106.59	111	3.4	2.88	125.40
09/09/96	1,875	7.67	19.6	1.29	129.58	114	3.2	3.41	161.98
09/10/96	1,834	7.64	19.7	1.24	127.32	114	3.2	3.35	159.15
09/11/96	1,867	6.75	19.8	1.03	103.93	76	3.2	4.10	129.91
09/12/96	1,811	6.65	18.9	1.0	103.98	76	3.4	4.10	122.33
09/13/96	1,847	6.73	18.5	1.03	105.04	76	3.4	4.15	123.58
09/14/96	1,869	6.85	19	1.01	101.77	76	3.2	4.02	127.21
09/15/96	1,839	6.72	20.3	1.1	112.64	57	3.0	5.93	150.19
09/16/96	1,846	6.92	21.1	1.16	118.33	57	2.8	6.23	169.04
09/17/96	1,828	6.71	19.4	1.08	111.26	76	3.2	4.39	139.07
09/18/96	1,823	6.96	18	0.61	63.02	73	3.4	2.59	74.14
09/19/96	1,820	6.89	16.4	1.29	133.47	78	3.8	5.13	140.50
09/20/96	1,845	7.00	15.6	1.17	119.47	92	4.0	3.90	119.47
09/21/96	1,860	700	15.7	1.03	104.31	92	40	3.40	104.31
09/22/96	1,852	7.06	15.8	0.96	97.65	90	4.0	3.26	97.65
09/23/96	1,855	6.62	15.5	1.18	119.84	76	4.0	4.73	119.84
09/24/96	1,843	7.43	15.1	1.12	114.49	92	4.0	3.73	114.49
09/25/96	1,859	7.27	14.9	1.3	131.72	140	4.4	2.82	119.74
09/26/96	1,835	7.38	14.1	1.12	114.97	137	4.4	2.52	104.52
09/27/96	1,845	7.41	13.3	1.05	107.19	137	4.8	2.35	89.32
09/28/96	1,860	7.28	13	1.31	132.69	140	4.8	2.84	110.57
09/29/96	1,855	7.43	13.3	1.58	160.47	144	4.8	3.34	133.73
09/30/96	1,824	7.42	14	1.45	149.73	144	4.4	3.12	136.11

[1] $3.0 \times \frac{CT_{actual}}{CT_{3\text{-log, }Giardia}}$ [2] $4.0 \times \frac{CT_{actual}}{CT_{4\text{-log, viruses}}}$

3.6.3 Determination of Disinfection Profile and Benchmark

Listed below are tasks needed to develop the disinfection profile and set the benchmark:

- Repeat the above calculations for 1, 2, or 3 years of available or collected data.
- Arrange total plant estimated log inactivation in chronological order, beginning with the earliest data.
- Develop a graphical plot of estimated log inactivation versus time (i.e., disinfection profile). Inactivation should be on the y-axis and time (days) should be on the x-axis.
- Calculate the average (arithmetic mean) estimated disinfection log inactivation for each calendar month.
- Determine the calendar month in a year with the lowest average log inactivation. The lowest average month becomes the "critical period" for that year.

Table 3-10 lists the critical periods for this plant in each year and the corresponding log inactivation.

Table 3-10. Critical Periods for Existing Disinfection Practice

Year	Month of Critical Period for *Giardia* Inactivation	Log Inactivation of *Giardia*	Month of Critical Period for Viral Inactivation	Log Inactivation of Viruses
1994	February	2.0	February	63.3
1995	February	1.5	February	50.7
1996	January	1.6	February	50.8

The benchmark is the lowest monthly average log inactivation and is calculated as the average of the three critical periods. For the plant illustrated in Table 3-10, the benchmarks for *Giardia* and viruses are calculated as follows:

$$\text{Benchmark}_{Giardia} = \text{Average Log Inactivation of Critical Periods}$$
$$= (2 + 1.5 + 1.6)/3$$
$$= 1.7$$

$$\text{Benchmark}_{viruses} = \text{Average Log Inactivation of Critical Periods}$$
$$= (63.3 + 50.7 + 50.8)/3$$
$$= 54.9$$

The disinfection profiles and benchmarks based on *Giardia* and viruses are illustrated in Figures 3-6 and 3-7.

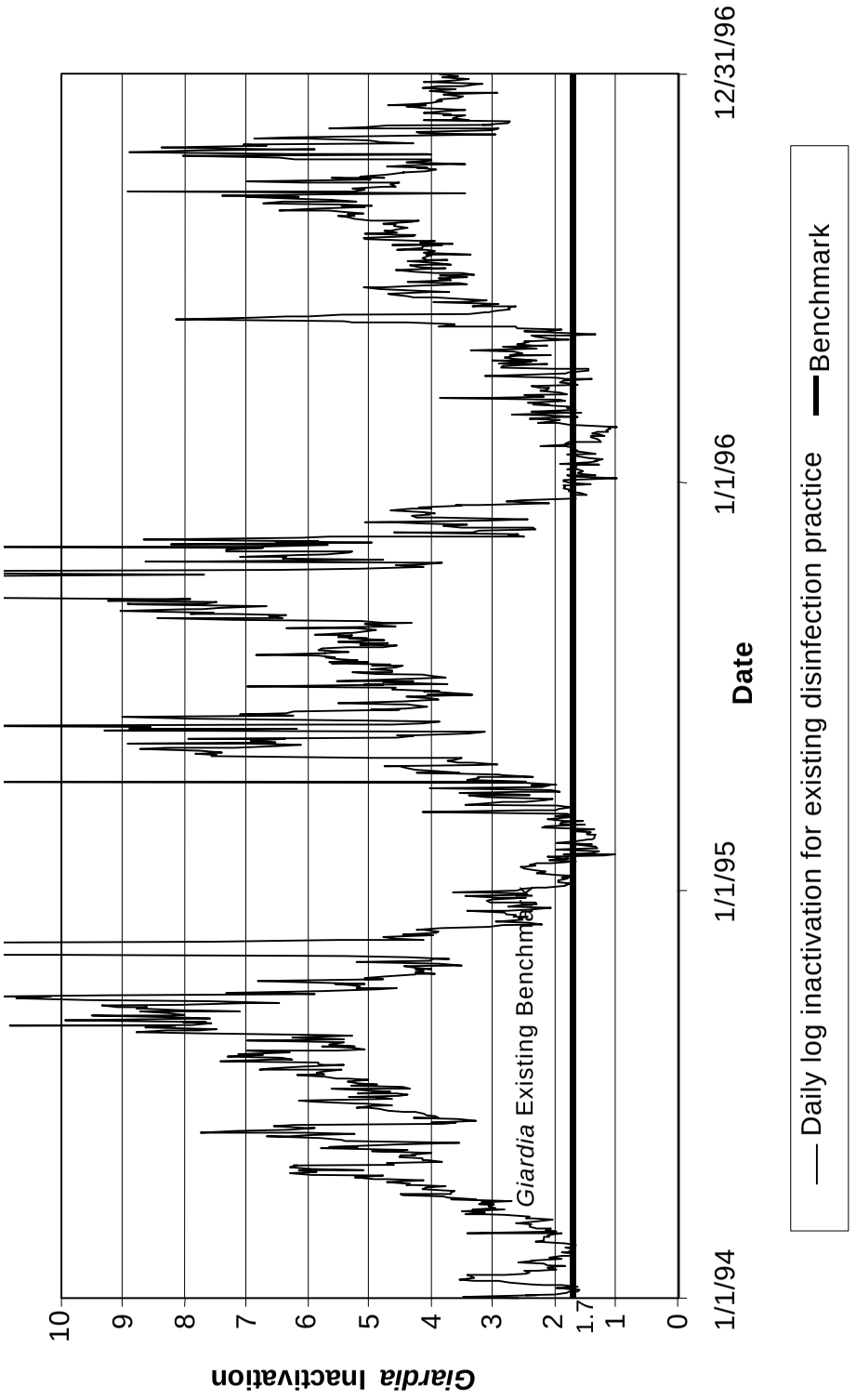

Figure 3-6. Log *Giardia* Inactivation for Existing Disinfection Practice

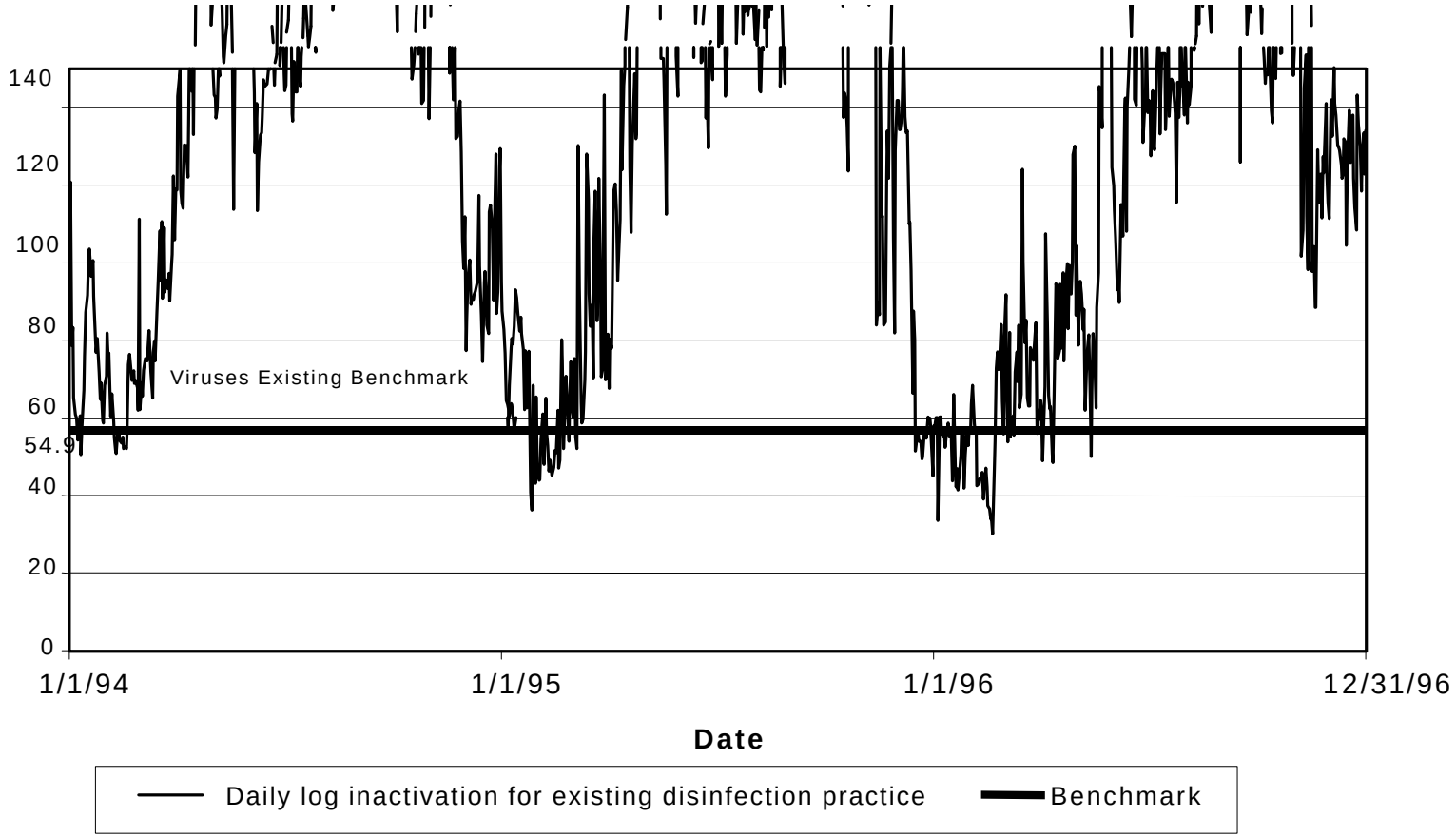

Figure 3-7. Log Virus Inactivation for Existing Disinfection Practice

3.6.4 Modification of Disinfection Practice

In this example for a 40 mgd plant, the utility has determined that DBP concentrations exceed profiling applicability triggers and has developed a profile. It then intends to modify its disinfection practice to control DBPs. The plant is considering two options for control:

Option 1

- Replace pre-oxidation using chlorine with potassium permanganate preoxidation. Although no disinfection credit is available for using potassium permanganate, the utility staff believes that it would effectively control tastes and odors. The point of chlorination is moved downstream of sedimentation to assist in the control of DBPs.
- Apply the chlorine dose after sedimentation to increase the chlorine residual by 20 percent to offset the loss in disinfection contact time.
- Add ammonia prior to the clearwell as in the original disinfection scheme.

A process diagram of Option 1 proposed modifications is shown in Figure 3-8.

Option 2

- Replace pre-oxidation using chlorine with potassium permanganate preoxidation.
- Add an ozone contactor just prior to rapid mix to compensate for the loss in disinfection credit associated with eliminating prechlorination. The ozone contactor would have a theoretical detention time of 1.3 minutes under the design flow of 40 mgd. The utility plans to operate under conditions providing the ozone residuals presented in Table 3-11. Table 3-11 illustrates CT calculations and log inactivation calculations under specific assumptions. Also, biologically active filtration to control AOC produced by ozonation will be used to control distribution system regrowth. Refer to the *Alternative Disinfectants and Oxidants Guidance Manual* (USEPA, 1999a) for more information.
- Move the point of chlorination just downstream of filtration to assist with the control of DBPs and virus inactivation.
- Add ammonia prior to the clearwell as in the original disinfection scheme.

A process diagram of Option 2 proposed modifications is shown in Figure 3-9.

Table 3-11. Example Log Inactivation Calculations for Multi-Stage Ozone Contactor

Ozone Contact Chamber	Flow Direction	Volume (gallons)	Theoretical Detention Time (min)	Residual Ozone Concentration (mg/L)	C used in CT (mg/L)	T/T10	T10 (min)	CT actual (mg*min/L)	CT 3-log, Giardia (mg*min/L), Temp = 6 °C	CT 4-log, virus (mg*min/L) Temp = 6 °C	Actual *Giardia* Log Inactivation	Actual Virus Log Inactivation
1a	Down	6193.5	0.58	0.8		0.6	0.35	N/A*			0.5*	1.0*
1b	Up	6193.5	0.58	0.65	0.65	0.6	0.35	0.23	1.81	1.16	0.38	0.78
2a	Down	6193.5	0.58	0.55	0.275	0.6	0.35	0.10	1.81	1.16	0.16	0.33
2b	Up	6193.5	0.58	0.55	0.55	0.6	0.35	0.19	1.81	1.16	0.32	0.66
3a	Down	6193.5	0.58	0.45	0.225	0.6	0.35	0.08	1.81	1.16	0.13	0.27
3b	Up	6193.5	0.58	0.4	0.4	0.6	0.35	0.14	1.81	1.16	0.23	0.48
Totals							2.1	0.73			1.71	3.53

Notes: The peak hourly flow rate was determined to be 10,651 gallons per minute. The C used in CT computations for downflow chambers where gas is applied is 1/2 of the measured ozone residual concentration.

* CT credit is not available in the downflow chamber of the first stage of an ozone contactor. If the ozone residual at the outlet of the first contactor is greater than 0.3 mg/L, then the Giardia and virus log inactivation credits are 0.5 and 1.0, respectively. If the ozone residual at the outlet is less than 0.3 but greater than 0.1 mg/L, then the Giardia and virus log inactivation credits are 0 and 1.0, respectively.

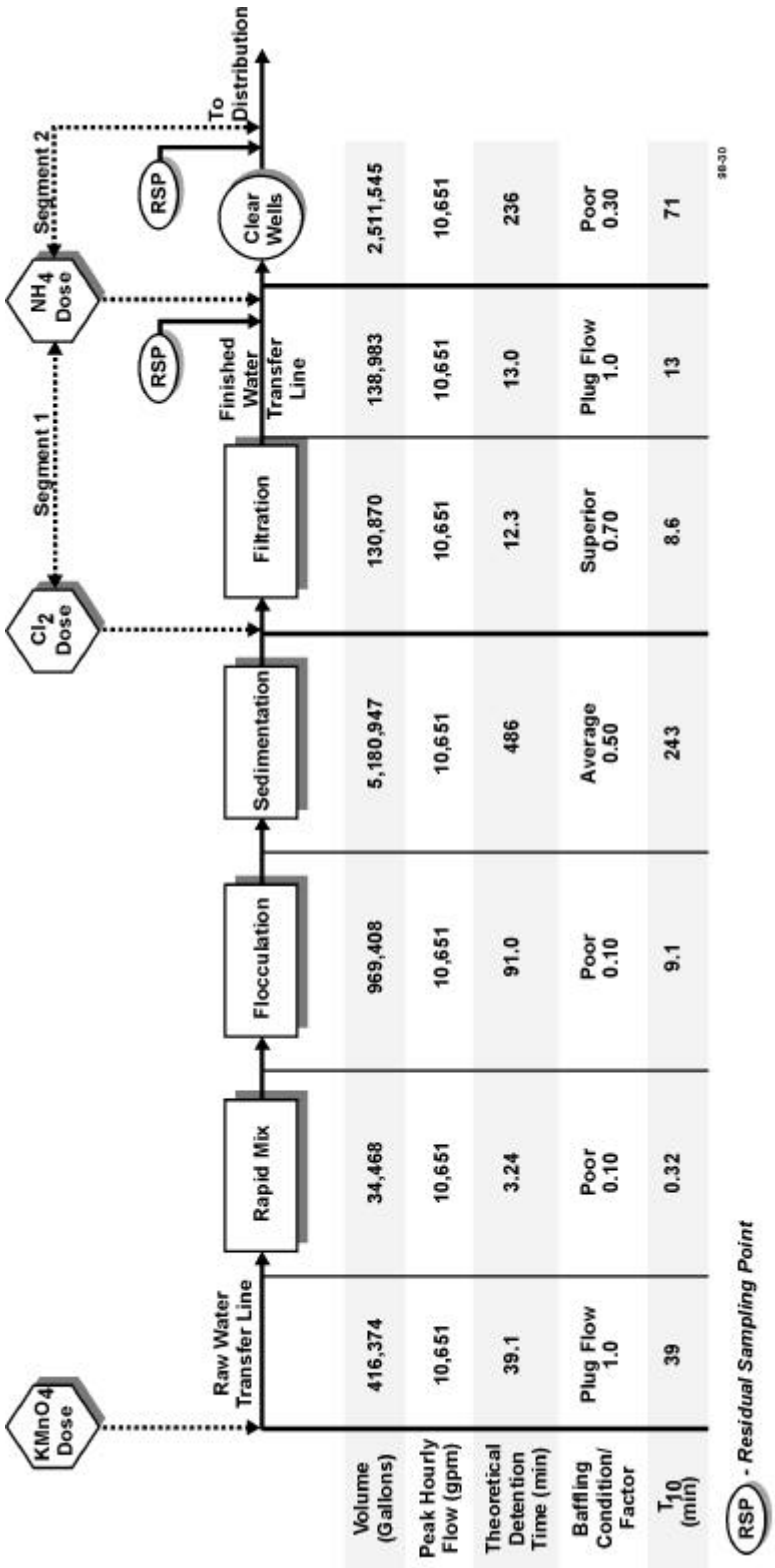

Figure 3-8. Option 1 Process Diagram

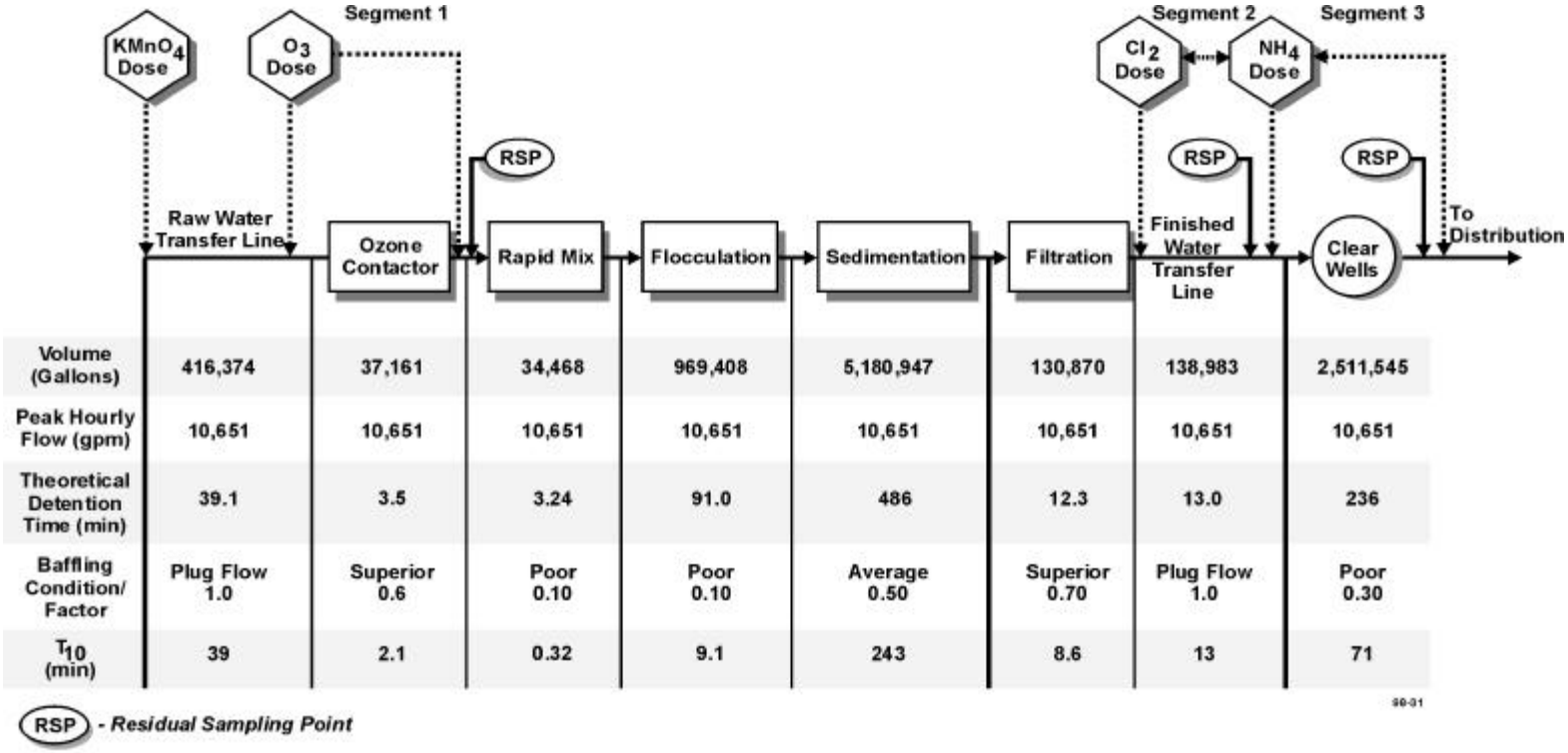

Figure C-4. Option 2 Process Diagram

Figure 3-9. Option 2 Process Diagram

A disinfection profile and alternative disinfection benchmark were developed for the first disinfection option (i.e., using potassium permanganate for pre-oxidation and using a chlorination point downstream for post-sedimentation). The proposed modification to disinfection does not include adding or switching to ozone, chloramines, or chlorine dioxide. Therefore, developing a profile and benchmark based on virus inactivation is not required. Table 3-12 lists the critical periods for each year and the corresponding log inactivation values.

Table 3-12. Critical Periods for Disinfection Option 1

Year	Month of Critical Period for *Giardia* Inactivation	Log Inactivation Of *Giardia*
1994	February	0.7
1995	February	0.5
1996	January	0.5

$$\text{Modification Benchmark}_{Giardia} = \text{Average Log Inactivation of Critical Periods}$$

$$= (0.7 + 0.5 + 0.5)/3$$

$$= 0.6$$

The daily log inactivations and modification benchmark for *Giardia* are illustrated in Figure 3-10. Note that the modification $\text{Benchmark}_{Giardia}$ for Option 1 is 0.6-log inactivation, which is lower than the existing $\text{Benchmark}_{Giardia}$ of 1.7-log inactivation. The system realizes that a higher free chlorine residual will improve the alternative benchmark level by about 0.2-log inactivation (say from 0.6 mg/L to 1.2 mg/L of free chlorine at 5°C and a pH of 8). These results indicate that Option 1 would not provide an equivalent degree of protection against *Giardia* as compared to the existing disinfection scheme.

A system is not prohibited from making a change that will result in a lower benchmark. Either the chlorine dose or contact time could be increased for this option to meet the current disinfection benchmark. A long-term option could involve increasing contact time by improving baffling conditions in the contact basin. The system may consult with the State on how to change its disinfection practice that will result in a lower inactivation level and at the same time protect public health as detailed in Chapter 5 (Using the Benchmark) and 6 (Alternative Disinfection Benchmark) of this guidance manual.

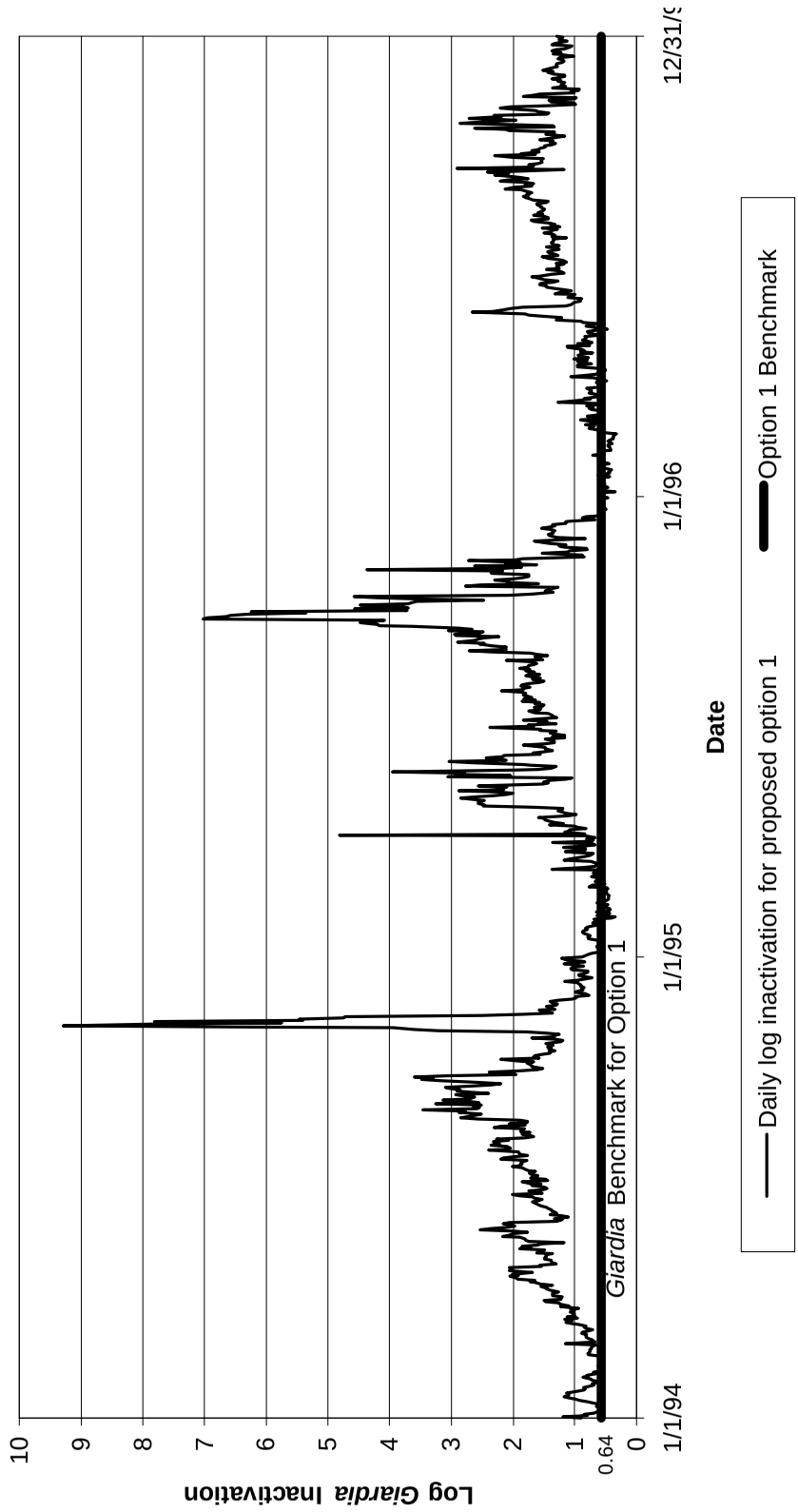

Figure 3-10. Log *Giardia* Inactivation for Disinfection Option 1

A disinfection profile and benchmark were also developed for the second disinfection option using the same methods as Option 1. Because Option 2 would add ozone to the disinfection system, profiling and benchmarking based on virus inactivation is also required. Table 3-13 lists the critical periods for each year and the corresponding log inactivation values

Table 3-13. Critical Periods for Disinfection Option 2

Year	Month of Critical Period for *Giardia* Inactivation	Log Inactivation of *Giardia*	Month of Critical Period for Virus Inactivation	Log Inactivation of Viruses
1994	February	2.6	February	19.3
1995	February	2.1	February	15.4
1996	January	2.1	February	15.5

$$\text{Modification Benchmark}_{Giardia} = \text{Average Log Inactivation of Critical Periods}$$

$$= (2.6 + 2.1 + 2.1)/3$$

$$= 2.3$$

$$\text{Modification Benchmark}_{viruses} = \text{Average Log Inactivation of Critical Periods}$$

$$= (19.3 + 15.4 + 15.5)/3$$

$$= 16.7$$

The daily log inactivations and benchmarks of *Giardia* and viruses are illustrated in Figures 3-11 and 3-12. Note that the Modification $\text{Benchmark}_{Giardia}$ for Option 2 achieves 2.3-log inactivation, which is higher than the existing $\text{Benchmark}_{Giardia}$ of 1.7-log inactivation. This indicates that Option 2 would provide equivalent or better microbial protection against *Giardia* when compared with the existing disinfection strategy.

However, the Modification $\text{Benchmark}_{viruses}$ for Option 2 achieves a log inactivation of 16.7, which is lower than the existing $\text{Benchmark}_{viruses}$ of 54.9-log inactivation. Consequently, Option 2 would not provide an equivalent degree of microbial protection against viruses when compared with the existing disinfection strategy, although 16.7-log inactivation of viruses would provide excellent protection against these pathogens. This indicates that the proposed disinfection strategy works against *Giardia*, but the utility would need to consult with the State prior to implementing an alternative benchmark for virus inactivation. See Chapter 6 for more information.

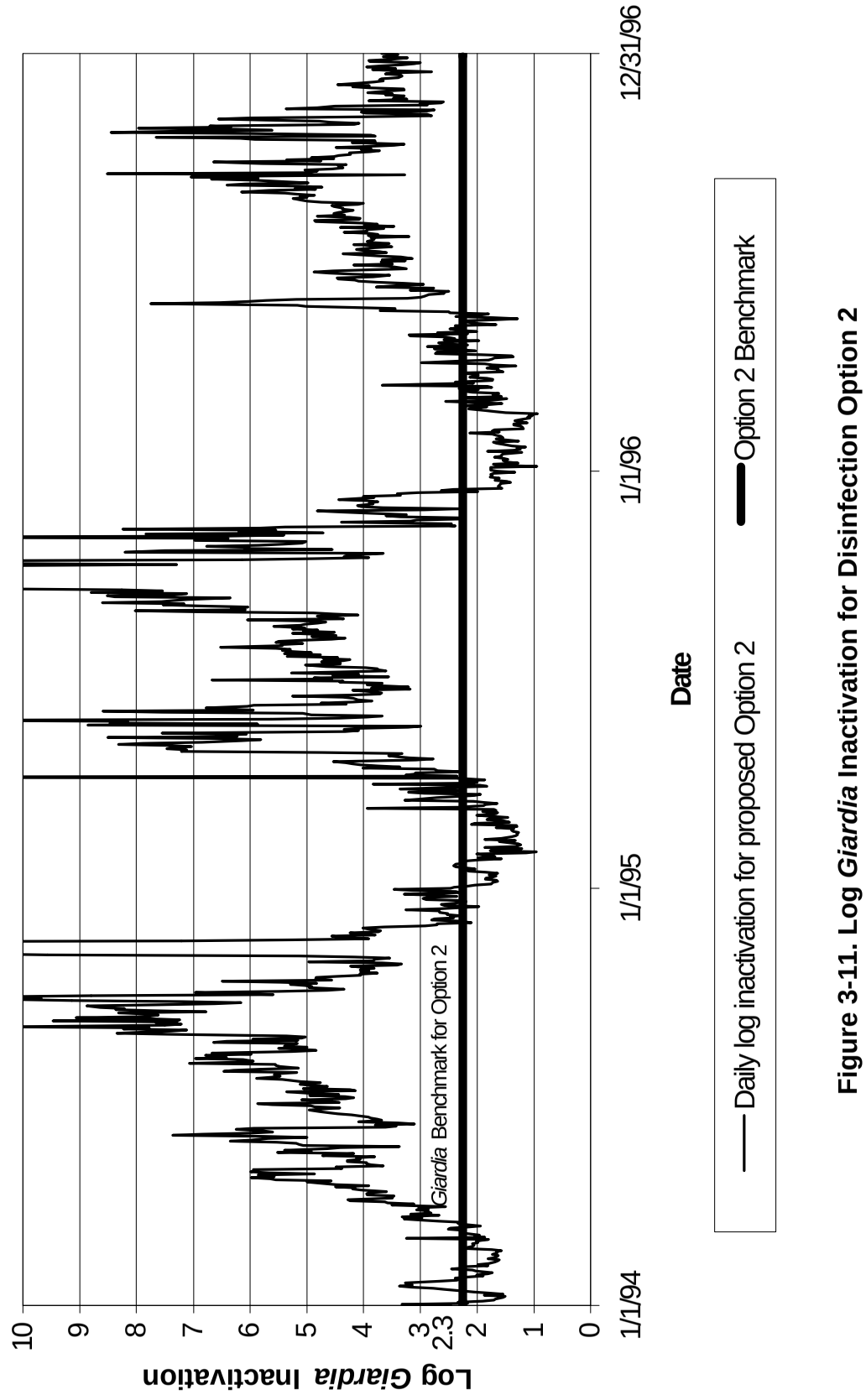

Figure 3-11. Log *Giardia* Inactivation for Disinfection Option 2

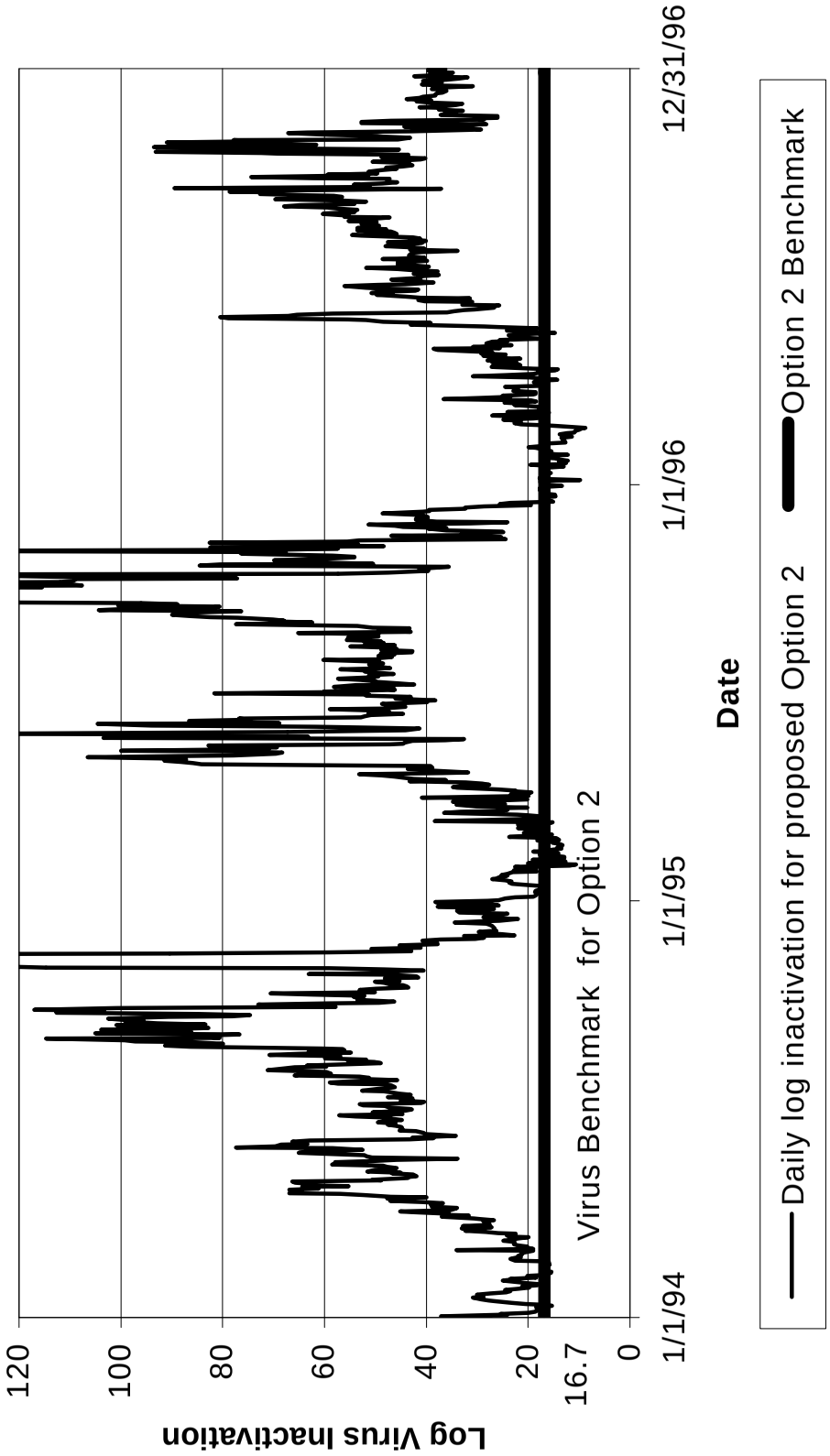

Figure 3-12. Log Virus Inactivation for Disinfection Option

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