



LONG TERM 2 ENHANCED SURFACE WATER TREATMENT RULE

TOOLBOX GUIDANCE MANUAL



Note on the Long Term 2 Enhanced Surface Water Treatment Rule Toolbox Guidance Manual, June 2003 Draft

Purpose: The purpose of this guidance manual, when finalized, is solely to provide technical information on applying the “Toolbox” of *Cryptosporidium* treatment and management strategies that are part of the upcoming Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). EPA is developing the LT2ESWTR to reduce the risk of *Cryptosporidium* and other microbial pathogens in drinking water. This regulation would require certain public water systems to provide additional treatment for *Cryptosporidium* by implementing one or more options from the Toolbox. Chapter 1 of this manual contains additional information about this regulation.

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Acronyms

AFOs	Animal Feeding Operations
AOC	Assimilable Organic Carbon
ASTM	American Society for Testing and Materials
BMPs	Best Management Practices
CAFOs	Concentrated Animal Feeding Operations
CCP	Composite Correction Program
CFE	Combined Filter Effluent
ClO ₂	Chlorine Dioxide
CPE	Comprehensive Performance Evaluation
CSO	Combined Sewer Overflow
CSTR	Continuous Stirred Tank Reactor
CT	Disinfectant Concentration x Contact Time
CTA	Comprehensive Technical Assistance
CWSs	Community Water Systems
DAF	Dissolved Air Flotation
DBPs	Disinfection Byproducts
DBPR	Disinfection Byproducts Rule
DEM	Digital Elevation Model
DOP	Demonstration of Performance
<i>E.coli</i>	<i>Escherichia coli</i>
EDTA	Ethylenediamine Tetra-Acetic Acid
EM	Electromagnetic
EPA	U.S. Environmental Protection Agency
FEMA	Federal Emergency Management Agency
GAC	Granular Activated Carbon
GIS	Geographical Information System
GPR	Ground Penetrating Radar
GWUDI	Ground Water Under the Direct Influence of Surface Water
HAA	Haloacetic acid
HAA5	The sum of five HAA species [monchloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, dibromoacetic acid]
HDT	Hydraulic Detention Time
HPCs	Heterotrophic Plate Counts
HUC	Hydrologic Unit Code
IDSE	Initial Distribution System Evaluation
IESWTR	Interim Enhanced Surface Water Treatment Rule
IFE	Individual Filter Effluent
IP	Induced Polarisation
k*	Ozone decay rate
k ₁₀	Log base ten lethality coefficient
LRAA	Locational Running Annual Average
LT1ESWTR	Long Term 1 Enhanced Surface Water Treatment Rule

LT2ESWTR	Long Term 2 Enhanced Surface Water Treatment Rule
MCL	Maximum Contaminant Level
M-DBP	Microbial and Disinfection Byproduct
MF/UF	Microfiltration and Ultrafiltration
mL	Milliliters
MRDLs	Maximum Residual Disinfectant Levels
MS4s	Municipal Separate Storm Sewer Systems
MTBE	Methyltertiarybutylether
NHDES	New Hampshire Department of Environmental Services
NOM	Natural Organic Matter
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NTNCWSs	Nontransient Noncommunity Water Systems
NTU	Nephelometric Turbidity Units
OSHA	Occupational Safety and Health Administration
PCR	Polymerase Chain Reaction
PWS	Public Water System
QA	Quality Assurance
QA/QC	Quality Assurance/Quality Control
RAA	Running Annual Average
SCD	Streaming Current Detectors
SDWA	Safe Drinking Water Act
SFA	Segmented Flow Analysis
SMP	Standard Monitoring Program
SOCs	Synthetic Organic Compounds
SOPs	Standard Operating Procedures
SP	Self-Potential
SPDES	State Pollution Discharge Elimination System
SSDR	Stock Solution Delivery Rate
SSOs	Sanitary Sewer Overflows
SSS	System-Specific Study
Stage 1 DBPR	Stage I Disinfection Byproducts Rule
SWTR	Surface Water Treatment Rule
TCE	Trichloroethylene
TEM	Pulse-transient Electromagnetic
THM	Trihalomethane
TNCWSs	Transient Noncommunity Water Systems
TOC	Total Organic Carbon
TTHM	Total Trihalomethanes
UFRVs	Unit Filter Run Volumes
UPS	Uninterruptible Power Supply
USDA	U.S. Department of Agriculture

USGS	U.S. Geological Survey
UV	Ultraviolet Light
UV ₂₅₄	Ultraviolet Light at a wavelength of 254 nm
WTP	Water Treatment Plant

1.0 Introduction

In establishing drinking water regulations for microbial and disinfection byproduct (M-DBP) control, the U.S. Environmental Protection Agency (EPA) is promoting a multi-barrier approach for treating drinking water. A multi-barrier treatment process provides a number of protective “layers” against contamination by using more than one method of prevention and treatment to remove or inactivate microorganisms and minimize disinfection byproducts (DBPs). To that end, EPA is publishing this guidance to help public water systems (PWSs) choose appropriate combinations of treatment processes for compliance with the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR).

The LT2ESWTR focuses on improved control of microbial contamination, specifically the protozoan parasite *Cryptosporidium*. Differing from previous drinking water regulations, the LT2ESWTR requirements for each system are based on the PWS’s vulnerability to contamination, as measured by the occurrence of *Cryptosporidium* in the source water. This “Microbial Framework” strategy stems from a recognition that only some systems may need to provide additional protection against *Cryptosporidium* and that such decisions should be made on a system-specific basis.

With this approach, systems initially conduct source water monitoring to determine average *Cryptosporidium* concentrations (small filtered systems first monitor for *E. coli* to determine if *Cryptosporidium* monitoring is required). Based on their monitoring results, systems are classified into different categories (or bins). The bins indicate the additional *Cryptosporidium* treatment requirements, if any, that must be met to comply with the rule. Systems required to provide additional treatment will choose from a “toolbox” of options consisting of treatment technologies, process optimization techniques, and management techniques to meet the requirements. Thus, this approach requires enhanced *Cryptosporidium* treatment for systems with higher vulnerability to *Cryptosporidium* contamination and provides several options for those systems to achieve compliance. These options are described in this manual.

1.1 Objectives

The primary objectives of this manual are to provide guidance to public water systems for selecting appropriate toolbox options and achieving compliance for each option. To accomplish these objectives, this manual will describe each toolbox option in terms of achieving *Cryptosporidium* treatment credit(s) and discuss design and operational issues systems should consider for each option.

1.2 Organization

This manual consists of fifteen chapters and appendices:

- Chapter 1 Introduction - The remainder of this chapter summarizes the LT2ESWTR, presents the bin classifications for conventional treatment plants, direct filtration plants, and plants with other treatment technologies (i.e., softening, slow sand filtration, and diatomaceous earth filtration), and defines those processes in the context of the LT2ESWTR.
- Chapters 2 - 14 Toolbox Options - These chapters describe each toolbox option and how systems can implement these options to achieve the associated *Cryptosporidium* treatment credit. Where applicable, basic design criteria are recommended to achieve a given log removal. Each chapter contains its own list of references.
- Appendix A Site Specific Determination of Contact Time for Chlorine Dioxide and Ozone - describes the different elements of a site specific study to generate a set of chlorine dioxide or ozone CT values for that site and discusses some of the issues involved in the statistical analysis of the results.
- Appendix B Ozone CT Methods - describes the Segmented Flow Analysis and Extended-CSTR methods to calculate the CT inactivation credits with ozone.
- Appendix C Measuring Ozone Residual - discusses ozone residual sample collection, measurement, and online ozone residual analyzer calibration.
- Appendix D Derivation of SFA and Extended CSTR Equations - provides derivations for the Segmented Flow Analysis equation and the equation used to calculate k^* .
- Appendix E Watershed Control Best Management Practices (BMPs) - provides a list of programmatic resources and guidance available to assist systems in building partnerships and implementing watershed protection activities.

1.3 Existing Regulations and Treatment Requirements

The following sections describe the predecessors to the LT2ESWTR, along with the Stage 1 Disinfectants and Disinfection Byproducts Rule (DBPR), which was promulgated to reduce the formation of DBPs in the plant and distribution system.

1.3.1 Surface Water Treatment Rule

Under the 1989 Surface Water Treatment Rule (SWTR) (54 FR 27486), EPA established treatment requirements for all PWSs using surface water or ground water under the direct influence of surface water (GWUDI) as a source. The requirements are intended to protect against the adverse health effects associated with *Giardia lamblia*, viruses, and *Legionella* and include the following:

- Maintenance of a disinfectant residual in water entering and within the distribution system.
- Removal/inactivation of at least 99.9 percent (3 log) of *Giardia* and 99.99 percent (4 log) of viruses.
- Filtration, unless systems meet specified avoidance criteria.
- For filtered systems, a turbidity limit for the combined filter effluent of 5 nephelometric turbidity units (NTUs) at any time and a limit of 0.5 NTU in 95 percent of measurements each month for treatment plants using conventional treatment or direct filtration (with separate standards for other filtration technologies). These requirements were superseded by the 1998 IESWTR and the 2002 LT1ESWTR.
- Watershed control programs and water quality requirements for unfiltered systems.

1.3.2 Interim Enhanced Surface Water Treatment Rule

The Interim Enhanced Surface Water Treatment Rule (IESWTR) (63 FR 69478) applies to PWSs serving at least 10,000 people and using surface water or GWUDI as a source. These systems were to comply with the IESWTR by January 2002. The requirements and guidelines include:

- Removal of 99 percent (2 log) of *Cryptosporidium* for systems that provide filtration
- For treatment plants using conventional treatment or direct filtration, a turbidity performance standard for the combined effluent of filters of 1 NTU as a maximum and 0.3 NTU as a maximum in 95 percent of monthly measurements, based on 4-hour monitoring (these limits supersede the SWTR turbidity limits)
- Continuous monitoring of individual filter effluent turbidity in conventional and direct filtration plants and recording of turbidity readings every 15 minutes

- A disinfection benchmark to assess the level of microbial protection provided before facilities change their disinfection practices to meet the requirements of the Stage 1 DBPR
- Inclusion of *Cryptosporidium* in the definition of GWUDI and in the watershed control requirements for unfiltered PWSs
- All new finished water reservoirs must be covered.

1.3.3 Stage 1 Disinfectants and Disinfection Byproducts Rule

Pursuant to requirements under the Safe Drinking Water Act (SDWA), EPA developed interrelated regulations to control microbial pathogens and disinfectants/DBPs in drinking water. These rules, collectively known as the M-DBP rules, are intended to address complex risk trade-offs between the two different types of contaminants. EPA promulgated the IESWTR concurrently with the Stage 1 DBPR so that systems could coordinate their responses to the risks posed by DBPs and microbial pathogens.

The 1998 Stage 1 DBPR (63 FR 69390) applies to all community water systems (CWSs) and nontransient noncommunity water systems (NTNCWSs) that add a chemical disinfectant to their water. Certain requirements in the rule also apply to transient noncommunity water systems (TNCWSs). Surface water and GWUDI systems serving at least 10,000 people were required to comply with the rule by January 2002. All other systems (including ground water systems) must comply by January 2004.

The Stage 1 DBPR sets maximum residual disinfectant levels (MRDLs) for chlorine, chloramines, and chlorine dioxide; and maximum contaminant levels (MCLs) for total trihalomethanes (TTHM), haloacetic acids (HAA5), bromate, and chlorite. The MRDLs and MCLs, except those for chlorite and chlorine dioxide, are calculated as running annual averages. For conventional filtration systems, enhanced coagulation/softening is the best available treatment technique for removal of DBP precursors.

1.3.4 Long Term 1 Enhanced Surface Water Treatment Rule

The Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR) (67 FR 1811) was promulgated in 2002 and extends most of the requirements of the IESWTR to surface water and GWUDI systems serving fewer than 10,000 people.

1.4 Microbial-Disinfection Byproduct Rule Summary

In keeping with a phased M-DBP strategy, EPA developed the Stage 2 DBPR and LT2ESWTR. These rules are summarized below.

1.4.1 Stage 2 Disinfectant and Disinfection Byproduct Rule

The requirements of the Stage 2 DBPR apply to all community water systems (CWSs) and nontransient noncommunity water systems (NTNCWSs)—both ground and surface water systems—that add a disinfectant other than ultraviolet light (UV), or that deliver water that has been treated with a disinfectant other than UV.

Initial Distribution System Evaluations

The Stage 2 DBPR is designed to reduce DBP occurrence peaks in the distribution system by changing compliance monitoring requirements and the procedure for determining compliance. Compliance monitoring will be preceded by an initial distribution system evaluation (IDSE) to identify compliance monitoring locations that represent high TTHM and HAA5 levels. The IDSE consists of either a standard monitoring program (SMP) or a system-specific study (SSS). NTNCWSs serving fewer than 10,000 people are not required to perform an IDSE, and other systems may receive waivers from the IDSE requirement.

Compliance Determination and Schedule

The Stage 2 DBPR changes the way sampling results are averaged to determine compliance. The determination for the Stage 2 DBPR is based on a locational running annual average (LRAA) (i.e., compliance must be met at *each* monitoring location) instead of the system-wide running annual average (RAA) used under the Stage 1 DBPR.

The Stage 2 DBPR will be implemented in two phases, Stage 2A and Stage 2B. Under Stage 2A, all systems must comply with TTHM/HAA5 MCLs of 120/100 µg/L measured as LRAAs at each Stage 1 DBPR monitoring site, while continuing to comply with the Stage 1 DBPR MCLs of 80/60 µg/L measured as RAAs. Under Stage 2B, systems must comply with TTHM/HAA5 MCLs of 80/60 µg/L at locations identified under the IDSE.

Compliance Monitoring

Systems will continue to monitor at their Stage 1 DBPR compliance monitoring sites for the Stage 2A DBPR. The Stage 2B DBPR compliance monitoring sites will be determined from the results of the IDSE. Stage 2B compliance monitoring requirements (number of sites and frequency of

sampling) will be similar to the Stage 1 DBPR requirements for most, but not all, systems. Some small systems will have to add an additional monitoring location if their highest TTHM and highest HAA5 site do not occur at the same location.

Significant Excursion Evaluations

Because Stage 2 DBPR MCL compliance is based on an annual average of DBP measurements, a system could from time to time have DBP levels significantly higher than the MCL (referred to as a significant excursion) while still being in compliance. This is because the high concentration could be averaged with lower concentrations at a given location. If a significant excursion occurs, a system must conduct a significant excursion evaluation and discuss the evaluation with the State no later than the next sanitary survey.

1.4.2 Long Term 2 Enhanced Surface Water Treatment Rule

1.4.2.1 Filtered Systems

The LT2ESWTR requires systems that use a surface water or GWUDI source (referred to collectively in this manual as surface water systems) and provide filtration to conduct source water monitoring to determine average *Cryptosporidium* concentrations, unless they have historical *Cryptosporidium* data equivalent to what is required under the LT2ESWTR (40 CFR 141.701(a)). Based on its average source water *Cryptosporidium* concentration, a system will be classified in one of four possible bins. A system's bin assignment determines the extent of any additional *Cryptosporidium* treatment requirements. The rule requires systems to comply with additional treatment requirements by using one or more management or treatment techniques from the toolbox of options (40 CFR 141.720(b)). The process is described in more detail below; the full monitoring requirements are described in the *Source Water Monitoring Guidance Manual for Public Water Systems for the Long Term 2 Enhanced Surface Water Treatment Rule* (USEPA 2003).

Monitoring Requirements

The LT2ESWTR specifies two monitoring schemes for filtered systems serving at least 10,000 people. The first is that the system collect at least 24 samples, but not more than 47 samples, over a 2-year period and base the bin assignment on the maximum running annual average (RAA) (40 CFR 141.709(b(1))). (The first RAA will be the average of the results of the first 12 months of monitoring; the second RAA will be the average of results from months 2–13, the third will be the average of concentrations from months 3–14, etc.) Alternatively, systems may collect two or more samples per month over the 2-year period and use the average of all samples to determine bin placement (40 CFR 141.709(b(1))).

For filtered systems serving fewer than 10,000 people, the LT2ESWTR requires those systems to first monitor for *E. coli* (or an indicator approved by the State) at least every two weeks for 12 months; based on the results, they may be required to conduct *Cryptosporidium* monitoring at least twice a month for 12 months (40 CFR 141.701(e)). Systems that, based on their *E. coli* results, do *not* have to monitor *Cryptosporidium* are placed in Bin 1 (see Table 1.1). Systems that must conduct *Cryptosporidium* monitoring include the following (40 CFR 141.702(b)):

- Systems that use lakes or reservoirs as sources and that have an average *E. coli* concentration of more than 10 *E. coli* per 100 milliliters (mL).
- Those systems that use flowing streams as sources and that have an average *E. coli* concentration of more than 50 *E. coli* per 100 mL.

For those systems triggered into *Cryptosporidium* monitoring, bin assignment is based on the average *Cryptosporidium* concentration of the 24 required samples (40 CFR 141.709(b(3))).

Bin Classification

Table 1.1 presents the bin classifications and their corresponding additional treatment requirements for all filtered systems (40 CFR 141.709 and 40 CFR 141.720). Systems with average *Cryptosporidium* concentrations of less than 0.075 oocysts per liter are placed in Bin 1, for which no additional treatment is required. For concentrations of 0.075 or more, additional treatment is required on top of that required by existing rules. The additional treatment required for each bin, specified in terms of log removal, depends on the type of treatment already in place in the system.

Table 1.1 Bin Requirements for Filtered Plants¹

If your <i>Cryptosporidium</i> concentration (oocysts/L) is...	Your bin classification is...	And if you use the following filtration treatment in full compliance with existing regulations, then your <i>additional</i> treatment requirements are...			
		Conventional Filtration Treatment (includes softening)	Direct Filtration	Slow Sand or Diatomaceous Earth Filtration	Alternative Filtration Technologies
< 0.075	1	No additional treatment	No additional treatment	No additional treatment	No additional treatment
≥ 0.075 and < 1.0	2	1 log treatment ²	1.5 log treatment ²	1 log treatment ²	As determined by the State ^{2,4}
≥ 1.0 and < 3.0	3	2 log treatment ³	2.5 log treatment ³	2 log treatment ³	As determined by the State ^{3,5}
≥ 3.0	4	2.5 log treatment ³	3 log treatment ³	2.5 log treatment ³	As determined by the State ^{3,6}

¹ (40 CFR 141.709 and 40 CFR 141.720)

² Systems may use any technology or combination of technologies from the microbial toolbox.

³ Systems must achieve at least 1 log of the required treatment using ozone, chlorine dioxide, UV, membranes, bag/cartridge filters, or bank filtration.

⁴ Total *Cryptosporidium* treatment must be at least 4.0 log.

⁵ Total *Cryptosporidium* treatment must be at least 5.0 log.

⁶ Total *Cryptosporidium* treatment must be at least 5.5 log.

Additional Treatment Requirements

The total *Cryptosporidium* treatment required for Bins 2, 3, and 4 is 4.0 log, 5.0 log, and 5.5 log, respectively. The additional treatment requirements in Table 1.1 are based on a determination that **conventional, slow sand, and diatomaceous earth** filtration plants in compliance with the IESWTR or LT1ESWTR achieve an average of **3 log removal of *Cryptosporidium*** (the 2 log credit for *Cryptosporidium* under the IESWTR and LT1ESWTR is based on the *minimum* removal expected with these types of filtration). Therefore, conventional, slow sand, and diatomaceous earth filtration plants will require an additional 1.0 to 2.5 log additional treatment to meet the total removal requirement, depending on the bin they are placed in.

Conventional treatment is a treatment train with coagulation, flocculation, sedimentation, and granular media filtration. Sedimentation is defined in 40 CFR 141.2 as a process for removal of solids before filtration by gravity or separation. Solid/liquid separation processes with solids removal

capability include gravity sedimentation (traditional, plate, tube, ballasted sand), dissolved air flotation (DAF), solids contact clarifiers, and buoyant and non-buoyant media clarifiers.

Direct filtration plants have coagulation, flocculation, and filtration processes, like conventional treatment, but lack a sedimentation process. By providing a second pathogen barrier, a sedimentation basin enhances the overall removal efficiency and stability of the treatment train. EPA has determined that direct filtration plants achieve an average **2.5 log removal** of *Cryptosporidium*. Consequently, under the LT2ESWTR, direct filtration plants in Bins 2–4 must provide 0.5 log more in additional treatment than conventional plants to meet the total *Cryptosporidium* removal requirement.

The LT2ESWTR specifies that a State may award greater credit to a system demonstrating through a State-approved protocol that it reliably achieves a higher level of *Cryptosporidium* removal (40 CFR 141.727(c)). Conversely, a State may award less credit to a system where the State determines, based on site-specific information, that the system is not achieving the degree of *Cryptosporidium* removal indicated in Table 1.1 (40 CFR 141.727(c)).

For systems using alternative filtration technologies, such as bag or cartridge filters, the LT2ESWTR specifies that the State will determine additional treatment requirements based on the credit awarded to a particular technology. The additional treatment must be such that plants in Bins 2,3, and 4 achieve the total required *Cryptosporidium* reductions of 4.0, 5.0, and 5.5 log, respectively (40 CFR 141.720).

Systems in Bin 2 can meet additional *Cryptosporidium* treatment requirements by using an option or combination of options in the toolbox (40 CFR 141.720(b)). In Bins 3 and 4, systems must achieve at least 1 log of the additional treatment requirement through use of ozone, chlorine dioxide, ultraviolet light, membrane filtration, bag filtration, cartridge filtration, or bank filtration (40 CFR 141.720(c)).

1.4.2.2 Unfiltered Systems

All existing requirements for unfiltered systems under the SWTR (40 CFR, parts 141.71 and 72(a)) remain in effect. This includes disinfection to achieve at least 3 log inactivation of *Giardia* and 4 log inactivation of viruses and to maintain a disinfectant residual in the distribution system (e.g., free chlorine or chloramines). The IESWTR and LT1ESWTR did not change the disinfection requirements for unfiltered systems.

Under the LT2ESWTR, unfiltered systems are required to monitor their source water for *Cryptosporidium* to determine the amount of treatment required (40 CFR 141.701(d)). Systems serving 10,000 or more people must monitor at least once a month for two years (40 CFR 141.701(e)). Systems serving fewer than 10,000 people must monitor at least twice a month for one year (40 CFR 141.701(e)). All small unfiltered systems must monitor *Cryptosporidium*; there is no

exception based on *E. coli* monitoring results as there is for small filtered systems. These monitoring requirements are described in detail in the Source Water Monitoring Guidance Manual (USEPA 2003).

The arithmetic mean concentration of all *Cryptosporidium* samples taken is used to determine the amount of treatment required, as shown in Table 1.2 (40 CFR 141.721(a)). If the mean concentration is less than or equal to 0.01 oocysts/L, the system must provide 2 log inactivation of *Cryptosporidium* (40 CFR 141.721(b)). If the mean concentration of *Cryptosporidium* exceeds 0.01 oocysts/L, the system must provide at least 3 log inactivation of *Cryptosporidium* (40 CFR 141.721(b)).

Table 1.2 LT2ESWTR Treatment Requirements for Unfiltered Systems

Average <i>Cryptosporidium</i> Concentration (oocysts/liter)	Additional <i>Cryptosporidium</i> Inactivation Requirements
≤ 0.01	2 log ¹
> 0.01	3 log ¹

¹Overall disinfection requirements must be met with a minimum of two disinfectants.

The LT2ESWTR requires unfiltered systems to meet overall disinfection requirements (i.e., *Cryptosporidium*, *Giardia*, and virus inactivation) using a minimum of two disinfectants (40 CFR 141.721(d)). Disinfectants that can be used to meet this requirement include ozone, ultraviolet (UV) light, and chlorine dioxide. (Refer to the *UV Guidance Manual* for rule requirements and guidance regarding UV systems.) Further, each of the two disinfectants must achieve by itself the total inactivation required for one of the three pathogen types. For example, a system could use UV light to achieve 2 log inactivation of *Cryptosporidium* and *Giardia*, and use chlorine to inactivate 1 log *Giardia* and 4 log viruses. In this case chlorine would achieve the total inactivation required for viruses, while UV light would achieve the total inactivation required for *Cryptosporidium* and *Giardia*, and the two disinfectants together would meet the overall treatment requirements for viruses, *Giardia*, and *Cryptosporidium*.

1.4.2.3 Uncovered Finished Water Reservoirs

The LT2ESWTR requires systems with uncovered finished water reservoirs to cover the uncovered finished water reservoir, treat the reservoir discharge to the distribution system to achieve a 4 log virus inactivation, or implement a risk mitigation plan (40 CFR 141.724). The LT2ESWTR specifies that risk mitigation plans address physical access, surface water run-off, animal and bird waste, and continuous water quality assessment (40 CFR 141.724(a)(3)).

1.5 Summary of Microbial Toolbox Options

The LT2ESWTR requires systems to use one or more of the microbial toolbox options described in Table 1.3 (40 CFR 141.722). Components of the toolbox include watershed control programs, alternative sources, pretreatment process, additional filtration barriers, inactivation technologies, and enhanced plant performance. The intent of the toolbox is to provide systems with flexibility in selecting cost-effective LT2ESWTR compliance strategies.

In most cases, systems will receive presumptive log credit for a toolbox option by demonstrating compliance with required design and implementation criteria. The demonstration of performance option allows States to approve a treatment credit greater than the presumptive log credit based on a site-specific or technology-specific demonstration of performance (40 CFR 141.727(c)).

Systems may use a combination of toolbox options to achieve the required log treatment. For example, a conventional filtration system assigned to Bin 3, requiring an additional 2 log treatment, can implement ozone with a contact time and concentration yielding 1.5 log credit and achieve the requirements for combined filter performance, thus receiving an additional 0.5 log credit for a total of 2 log credit.

Table 1.3 Summary of Microbial Toolbox Options with Available Log Credits and Design/Implementation Criteria

Toolbox Option	<i>Cryptosporidium</i> Treatment Credit with Design and Implementation Criteria
Source Toolbox Components	
Watershed control program	0.5 log credit for State approved program comprised of EPA specified elements. Specific criteria are in 40 CFR 141.725(a). See Chapter 2 of this manual.
Alternative source/ intake management	No presumptive credit. Systems may conduct simultaneous monitoring for LT2ESWTR bin classification at alternative intake locations or under alternative intake management strategies. See 40 CFR 141.725(b). See Chapter 3.
Pre-Filtration Toolbox Components	
Bank filtration	0.5 log credit for 25 foot setback; 1.0 log credit for 50 foot setback. Aquifer must be unconsolidated sand containing at least 10% fines. Average turbidity in wells must be <1 NTU. Systems with existing wells must monitor well effluent to determine bin classification and are not eligible for presumptive credit. See 40 CFR 141.726(c). See Chapter 4.

Toolbox Option	<i>Cryptosporidium</i> Treatment Credit with Design and Implementation Criteria
Presedimentation basin with coagulation	0.5 log credit for new basins with continuous operation and coagulant addition. Basins must achieve 0.5 log turbidity reduction based on the monthly mean of daily measurements in 11 of the 12 previous months. All flow must pass through basins. Systems with existing pre-sed basins must monitor after basins to determine bin classification and are not eligible for presumptive credit. See 40 CFR 141.726(a). See Chapter 5.
Two-stage lime softening	0.5 log credit for two-stage softening with coagulant addition. Coagulant must be present in both clarifiers and includes metal salts, polymers, lime, or magnesium precipitation. Both clarifiers must treat 100% of flow. See 40 CFR 141.726(b). See Chapter 6.
Treatment Performance Toolbox Components	
Combined filter performance	0.5 log credit for combined filter effluent turbidity ≤ 0.15 NTU in 95% of samples each month. See 40 CFR 141.727(a). See Chapter 7.
Individual filter performance	1.0 log credit for individual filter effluent turbidity ≤ 0.1 NTU in 95% of daily maximum samples each month (excluding 15 minutes following backwash) and no filter >0.3 NTU in two consecutive measurements taken 15 minutes apart. See 40 CFR 141.727(b). See Chapter 7.
Demonstration of performance	Credit based on a demonstration to the State through State-approved protocol. See 40 CFR 141.727(c). See Chapter 12.
Additional Filtration Toolbox Components	
Bag filters	1 log credit with demonstration of at least 2 log removal efficiency in challenge test; Specific criteria are in 40 CFR 141.728(a). See Chapter 8.
Cartridge filters	2 log credit with demonstration of at least 3 log removal efficiency in challenge test; Specific criteria are in 40 CFR 141.728(a). See Chapter 8.
Membrane filtration	Log removal credit up to the lower value of the removal efficiency demonstrated during the challenge test if verified by direct integrity testing. See 40 CFR 141.728(b). See the Guidance Manual for Membrane Filtration.
Second stage filtration	0.5 log credit for a second separate filtration stage; treatment train must include coagulation prior to first filter. No presumptive credit for roughing filters. See 40 CFR 141.728(c). See Chapter 9.
Slow sand filters	2.5 log credit for second separate filtration process. No disinfectant residual present in influent. See 40 CFR 141.728(d). See Chapter 9.
Inactivation Toolbox Components	
Chlorine dioxide	Log credit based on demonstration of compliance with CT tables. See 40 CFR 141.729(b). See Chapter 10.
Ozone	Log credit based on demonstration of compliance with CT tables. See 40 CFR 141.729(c). See Chapter 11.

UV	Log credit based on demonstration of compliance with UV dose table; reactor testing required to establish validated operating conditions. See 40 CFR 141.729(d). See UV Guidance Manual.
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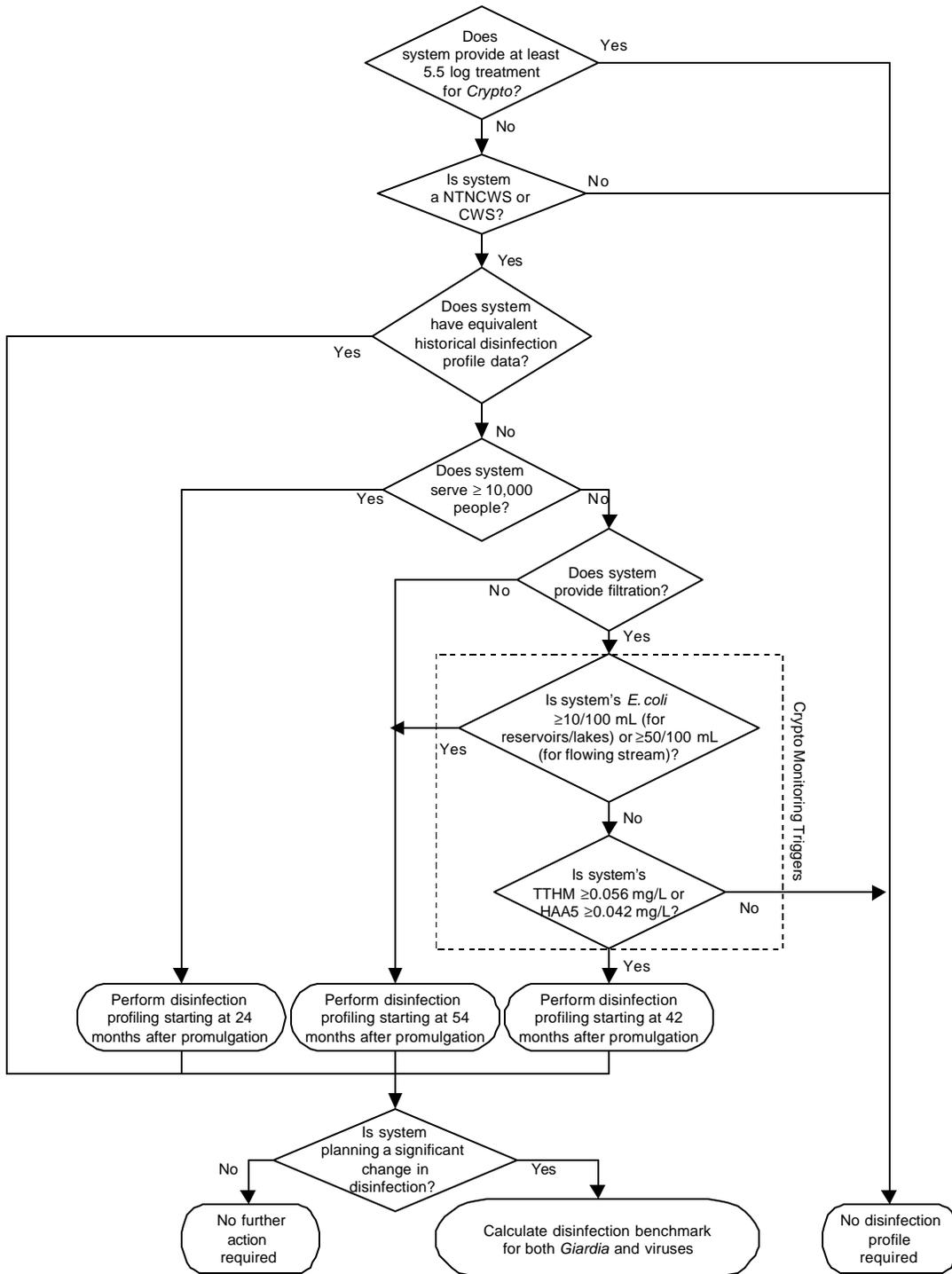
1.6 Disinfection Profiling and Benchmarking

The purpose of a disinfection benchmark is to ensure that when a system makes a change to its disinfection processes, it does not compromise the adequacy of existing microbial protection. A disinfection profile is a graphical representation of a system's level of *Giardia lamblia* and viral inactivation measured during the course of 1 or more year(s). A benchmark is the lowest monthly average of microbial inactivation during the disinfection profile period. This tool was introduced in the IESWTR (63 FR 69478 December 16, 1998) as a means for ensuring maintenance of microbial protection when systems made changes to address DBP control for the Stage 1 DBPR. The LT2ESWTR also includes a disinfection benchmark to ensure that any significant treatment change, whether for byproduct control under the Stage 2 DBPR, improved *Cryptosporidium* control under the LT2ESWTR, or both, does not significantly compromise existing *Giardia* and virus protection.

The profiling and benchmarking requirements under the LT2ESWTR are similar to those promulgated under IESWTR and LT1ESWTR and are applicable to: 1) systems required to conduct *Cryptosporidium* source water monitoring and 2) small surface water systems that do not have to conduct *Cryptosporidium* source water monitoring and have Stage 1 DBPR TTHM annual average results of at least 56 µg/L or HAA5 annual average results of at least 42 µg/L (40 CFR 141.711). Figure 1.1 presents a flow chart that can be used to determine if a system must develop a disinfection profile and benchmark. The LT2ESWTR requires these systems to prepare a disinfection profile that characterizes current levels of *Giardia lamblia* and virus inactivation throughout the plant over the course of one year (40 CFR 141.713). The profile may be developed using equivalent historical data. Subsequently, if a system proposes to make a significant change to its disinfection practice, then the LT2ESWTR requires the system to calculate a disinfection benchmark and consult with the State regarding how the proposed change will affect that benchmark (40 CFR 141.714).

Detailed guidance for conducting a disinfection profile and calculating a benchmark is provided in the IESWTR Disinfection Profiling and Benchmarking Guidance Manual for systems serving at least 10,000 people and the LT1ESWTR Disinfection Profiling and Benchmarking Guidance Manual for systems serving less than 10,000 people. A summary of the steps required to create a disinfection profile and calculate a benchmark are listed in the following two subsections.

Figure 1.1 Systems Required to Develop a Disinfection Profile and Benchmark



1.6.1 Creating a Disinfection Profile

The following steps describe how to calculate the *Giardia lamblia* and virus inactivations over a one year period:

- 1) Collect disinfectant residual, temperature, and pH (if chlorine is used) data daily for large systems and weekly for small systems for 12 consecutive months. The data should be collected after injection of the disinfectant and prior to the first customer (or next disinfectant injection point if applicable) during peak hourly flow.
- 2) Determine disinfectant contact time during peak hourly flow conditions measured between the point of application and the point of residual measurement.
- 3) Calculate CT_{calc} (product of disinfectant residual concentration and contact time) and from the CT tables determine the $CT_{99.9, Giardia}$ and $CT_{99.99, virus}$. (Chapter 12 contains more detailed information on calculating CT.)
- 4) Calculate the estimated log inactivation for *Giardia* and viruses according to the following equations:

$$\text{Log inactivation of } \textit{Giardia} = 3.0 \times CT_{calc} / CT_{99.9, \textit{Giardia}}$$

$$\text{Log inactivation of viruses} = 4.0 \times CT_{calc} / CT_{99.99, \textit{virus}}$$

- 5) Plot the total log inactivations from each day or week on a graph (*Giardia* and virus data on separate graphs). The resulting graph of 365 days or 52 weeks of data is the disinfection profile.

1.6.2 Disinfection Benchmark

A system that is required to develop a disinfection profile and that plans to make a significant change to its disinfection practice must calculate a benchmark and notify the State prior to making the change (40 CFR 141.714(a)). The LT2ESWTR defines significant changes to disinfection practices as changing the point of disinfection, the type of disinfectant, the process used, or other changes identified by the State.

The benchmark is a system's lowest monthly average microbial inactivation based on the disinfection profile. If the benchmark is substantially greater than the required inactivation (3.0 log

Giardia and 4.0 log virus), then a system may consider decreasing the amount of disinfectant added, contact time, or altering other disinfection practices, as long as it notifies the State.

1.7 Implementation Schedule

For those systems requiring additional treatment, the LT2ESWTR requires compliance by [72 months after promulgation] for systems serving 10,000 or more people and [102 months after promulgation] for systems serving less than 10,000 people (40 CFR 141.701(e)). States may grant an extra two years to systems that need to make capital improvements in order to meet the requirements. However, some toolbox options have additional requirements that must be met at an earlier date. Table 1.4 lists the requirements and compliance dates for each toolbox option for large and small systems, respectively.

Table 1.4 Compliance Dates¹

Toolbox Option	Systems must submit the following information	Schedule	
		Systems serving $\geq 10,000$ people	Systems serving $< 10,000$ people
Watershed Control Program (WCP)	Notify State of intention to develop WCP	No later than [date 48 months after date of publication of final rule in the <i>Federal Register</i>]	No later than [date 78 months after date of publication of final rule in the <i>Federal Register</i>]
	Submit initial WCP plan to State	No later than [date 60 months after date of publication of final rule in the <i>Federal Register</i>]	No later than [date 90 months after date of publication of final rule in the <i>Federal Register</i>]
	Annual report and State-approved watershed survey report	By a date determined by the State, every 12 months, beginning on [date 84 months after date of publication of final rule in the <i>Federal Register</i>].	By a date determined by the State, every 12 months, beginning on [date 114 months after date of publication of final rule in the <i>Federal Register</i>].
	Request for re-approval and report on the previous approval period.	Six months prior to the end of the current approval period or by a date previously determined by the State.	Six months prior to the end of the current approval period or by a date previously determined by the State.
Presedimentation (new basins)	Monthly verification of: <ul style="list-style-type: none"> • Continuous basin operation • Treatment of 100% of the flow • Continuous addition of a coagulant • At least 0.5 log removal of influent turbidity based on the monthly mean of daily turbidity readings for 11 of the 12 previous months 	Within 10 days following each month in which the monitoring was conducted, beginning on [date 72 months after date of publication of final rule in the <i>Federal Register</i>]	Within 10 days following each month in which the monitoring was conducted, beginning on [date 102 months after date of publication of final rule in the <i>Federal Register</i>]
Bank filtration	Initial demonstration of <ul style="list-style-type: none"> • Unconsolidated, predominantly sandy aquifer • Setback distance of at least 25 ft. (0.5 log) or 50 ft. (1.0 log) 	Initial demonstration no later than [date 72 months after date of publication of final rule in the <i>Federal Register</i>]	Initial demonstration no later than [date 102 months after date of publication of final rule in the <i>Federal Register</i>]

Toolbox Option	Systems must submit the following information	Schedule	
		Systems serving $\geq 10,000$ people	Systems serving $< 10,000$ people
	If monthly average of daily max turbidity is greater than 1 NTU, then system must report result and submit an assessment of the cause	Report within 30 days following the month in which monitoring was conducted, beginning [date 72 months after date of publication of final rule in the <i>Federal Register</i>]	Report within 30 days following the month in which monitoring was conducted, beginning [date 102 months after date of publication of final rule in the <i>Federal Register</i>]
Two-stage lime softening	Monthly verification of: <ul style="list-style-type: none"> • Continuous operation of a second clarification step between the primary clarifier and filter • Continuous presence of a coagulant in both primary and secondary clarifiers • Both clarifiers treat 100% of the plant flow 	Within 10 days following each month in which the monitoring was conducted, beginning on [date 72 months after date of publication of final rule in the <i>Federal Register</i>]	Within 10 days following each month in which the monitoring was conducted, beginning on [date 102 months after date of publication of final rule in the <i>Federal Register</i>]
Combined filter performance	Monthly verification of: <ul style="list-style-type: none"> • Combined filter effluent (CFE) turbidity levels less than or equal to 0.15 NTU in at least 95 percent of the 4 hour CFE measurements taken each month 	Within 10 days following each month in which the monitoring was conducted, beginning on [date 72 months after date of publication of final rule in the <i>Federal Register</i>]	Within 10 days following each month in which the monitoring was conducted, beginning on [date 102 months after date of publication of final rule in the <i>Federal Register</i>]
Individual filter performance	Monthly verification of: <ul style="list-style-type: none"> • Individual filter effluent (IFE) turbidity levels less than or equal to 0.1 NTU in at least 95 percent of all IFE measurements taken each month based on daily maximum (excluding 15 min period following start-up after backwash) • No individual filter greater than 0.3 NTU in two consecutive readings 15 minutes apart 	Within 10 days following each month in which the monitoring was conducted, beginning on [date 72 months after date of publication of final rule in the <i>Federal Register</i>]	Within 10 days following each month in which the monitoring was conducted, beginning on [date 102 months after date of publication of final rule in the <i>Federal Register</i>]
Membrane filtration	Results of verification testing demonstrating: <ul style="list-style-type: none"> • Removal efficiency established through challenge testing that meets rule criteria • Integrity testing and associated baseline 	No later than [date 72 months after date of publication of final rule in the <i>Federal Register</i>]	No later than [date 102 months after date of publication of final rule in the <i>Federal Register</i>]

Toolbox Option	Systems must submit the following information	Schedule	
		Systems serving $\geq 10,000$ people	Systems serving $< 10,000$ people
	Monthly report summarizing any direct integrity tests above the control limit, any indirect integrity monitoring results triggering direct integrity testing and the corrective action that was taken.	Within 10 days following the month in which monitoring was conducted, beginning [date 72 months after date of publication of final rule in the <i>Federal Register</i>]	Within 10 days following the month in which monitoring was conducted, beginning [date 102 months after date of publication of final rule in the <i>Federal Register</i>]
Bag filters and cartridge filters	Demonstration that the following criteria are met: <ul style="list-style-type: none"> • Process meets the definition of bag or cartridge filtration • Removal efficiency established through challenge testing that meets rule criteria • Challenge test shows at least 2 log removal for bag filters and 3 log removal for cartridge filters 	No later than [date 72 months after date of publication of final rule in the <i>Federal Register</i>]	No later than [date 102 months after date of publication of final rule in the <i>Federal Register</i>]
	Monthly verification that 100% of flow was filtered.	Within 10 days following the month in which monitoring was conducted, beginning [date 72 months after date of publication of final rule in the <i>Federal Register</i>]	Within 10 days following the month in which monitoring was conducted, beginning [date 102 months after date of publication of final rule in the <i>Federal Register</i>]
Second stage filtration	Monthly verification that 100% of flow was filtered.	Within 10 days following the month in which monitoring was conducted, beginning [date 72 months after date of publication of final rule in the <i>Federal Register</i>]	Within 10 days following the month in which monitoring was conducted, beginning [date 102 months after date of publication of final rule in the <i>Federal Register</i>]
Slow sand filtration	Monthly verification that 100% of flow was filtered.	Within 10 days following the month in which monitoring was conducted, beginning [date 72 months after date of publication of final rule in the <i>Federal Register</i>]	Within 10 days following the month in which monitoring was conducted, beginning [date 102 months after date of publication of final rule in the <i>Federal Register</i>]
Chlorine dioxide	Summary of CT values for each day based on Tables in 40 CFR 141.729(b).	Within 10 days following the month in which monitoring was conducted, beginning [date 72 months after date of publication of final rule in the <i>Federal Register</i>]	Within 10 days following the month in which monitoring was conducted, beginning [date 102 months after date of publication of final rule in the <i>Federal Register</i>]

Toolbox Option	Systems must submit the following information	Schedule	
		Systems serving \geq 10,000 people	Systems serving < 10,000 people
Ozone	Summary of CT values for each day based on Tables in 40 CFR 141.729(c).	Within 10 days following the month in which monitoring was conducted, beginning [date 72 months after date of publication of final rule in the <i>Federal Register</i>]	Within 10 days following the month in which monitoring was conducted, beginning [date 102 months after date of publication of final rule in the <i>Federal Register</i>]
UV	Validation test results demonstrating operating conditions that achieve required UV dose.	No later than [date 72 months after date of publication of final rule in the <i>Federal Register</i>]	No later than [date 102 months after date of publication of final rule in the <i>Federal Register</i>]
	Monthly report summarizing the percentage of water entering the distribution system that was not treated by UV reactors operating within validated conditions.	Within 10 days following the month in which monitoring was conducted, beginning [date 72 months after date of publication of final rule in the <i>Federal Register</i>]	Within 10 days following the month in which monitoring was conducted, beginning [date 102 months after date of publication of final rule in the <i>Federal Register</i>]
Demonstration of Performance	Results from testing following a State approved protocol.	No later than [date 72 months after date of publication of final rule in the <i>Federal Register</i>]	No later than [date 102 months after date of publication of final rule in the <i>Federal Register</i>]
	As required by the State, monthly verification of operating within conditions of State approval for demonstration of performance credit.	Within 10 days following the month in which monitoring was conducted, beginning [date 72 months after date of publication of final rule in the <i>Federal Register</i>]	Within 10 days following the month in which monitoring was conducted, beginning [date 102 months after date of publication of final rule in the <i>Federal Register</i>]

¹(40 CFR 141.730)

2.0 Watershed Control Program

2.1 Introduction

A well-designed watershed control program can result in a reduction of overall microbial risk. The risk reduction is associated with the implementation of practices that reduce *Cryptosporidium* as well as other pathogens. Further, knowledge of the watershed and factors affecting microbial risk, including sources of pathogens, fate and transport of pathogens, and hydrology, can also help a system reduce microbial risk.

There are many potential sources of *Cryptosporidium* in watersheds, including sewage discharges and nonpoint sources associated with animal feces. The feasibility, effectiveness, and sustainability of control measures to reduce *Cryptosporidium* contamination of water sources will be site-specific. Consequently, the watershed control program credit centers on systems working with stakeholders in the watershed to develop a site-specific program, and State review and approval are required. This section is intended to assist water systems in developing their watershed control programs and States in assessing and approving these programs.

A watershed control program can serve an additional purpose—it can also be a component of a comprehensive source water protection program that addresses chemical and microbial contaminant threats. Much of the background information and preparation needed to develop a watershed control program and comprehensive source water protection program are already complete as a result of the source water assessments required under the 1996 Amendments to the Safe Drinking Water Act. Section 1453 of the Act required States to conduct source water assessments for all public water systems, including delineating the “boundaries of the areas providing source waters for PWSs and identifying the origins of regulated and certain unregulated contaminants in the delineated area to determine the susceptibility of the PWSs to such contaminants.” Information resulting from these assessments should be available from the States. Information may also be available in systems that have had watershed sanitary surveys done. These surveys are required as part of the Interim Enhanced Surface Water Treatment Rule (IESWTR), and some States have required them for years.

2.1.1 Credits

Filtered systems that develop a State-approved watershed control program designed to reduce the level of *Cryptosporidium* in the watershed can receive a 0.5 log credit towards the *Cryptosporidium* treatment requirements under the LT2ESTWR (40 CFR 141.722). The watershed control program credit can be added to the credit awarded for any other toolbox component.

The list below provides the organization for the rest of this chapter.

- 2.2 What Kinds of PWSs Should Implement Watershed Control Programs - discusses case studies of watershed control programs in place at different PWSs around the United States; describes advantages and disadvantages of implementing a watershed control program; and what to do if your system already has a watershed control program.
- 2.3 How Do I Apply for Approval - discusses procedure systems must follow to apply for approval to implement a watershed control program. The following procedures are described: notifying the State of intent to participate; initial approval of watershed control program; and maintaining approval of watershed control program.
- 2.4 Developing the Watershed Control Program Plan - discusses the factors systems should consider in determining the impact *Cryptosporidium* has on their water quality, along with descriptions of best management practices systems can use to protect their source water from *Cryptosporidium*. The following four areas are discussed: vulnerability analysis; analysis of control measures; writing the watershed control plan; and how States should assess plans.
- 2.5 Maintaining Approval of a Watershed Control Program - discusses annual watershed control program status report, State approved watershed sanitary survey, request for re-approval, and guidance to States on re-approval.

2.2 What Kinds of PWSs Should Implement Watershed Control Programs?

Many types of systems can benefit from a watershed control program. This section contains case studies of watershed control programs in place at different PWSs around the United States. These studies show how systems of different sizes and source water types and with varying regulatory authority have adopted watershed control programs to fit their specific needs. This section also describes advantages and disadvantages of implementing a watershed control program.

2.2.1 Case Studies of Existing Watershed Control Programs

Watershed control programs should be based on site-specific conditions. A successful program will address the unique combination of land use, land ownership, zoning, regulatory controls, contaminant sources, and natural characteristics of the watershed being considered. The size, ownership, and jurisdictional nature of the water utility will also affect the role it plays in the watershed control program (AWWARF 1991).

As shown by the case studies below, successful watershed control programs will vary significantly in their approach to source protection. The systems in the case studies did not focus specifically on *Cryptosporidium* but on controlling microbial point and non-point sources and other contaminants. However, many of the elements noted in these case studies may be useful in watershed control programs addressing *Cryptosporidium*. For more case studies, see *Protecting Sources of Drinking Water: Selected Case Studies in Watershed Management* (U.S. EPA 1999a).

Burlington, Vermont

Medium Surface Water PWS, Watershed Located in Multiple Jurisdictions

The City of Burlington has a population of 40,000 and is located on the shore of Lake Champlain, a 120-mile long, 12-mile wide lake that is the source of drinking water for the city and other municipalities. In such a large watershed with multiple landowners, it is difficult to control activities that affect water quality. Burlington addresses microbial pollution through a combination of land use control, reduction in combined sewer overflow, watershed restoration, and outreach.

Through Act 250, the State of Vermont regulates land use near lake shores and rivers, accounting for new wastewater treatment plants and sewer systems, timber management, impervious surface area, water withdrawal by ski areas for snowmaking, and other issues. To address combined sewer overflow problems that were affecting Lake Champlain water quality, the city increased the capacity of its main wastewater treatment plant and extended the outfall far into the lake to dilute the effluent. The city separated the sanitary and storm sewers at its smaller plants. Two streams feeding into the lake that suffer from poor water quality are currently undergoing restoration, including retrofitting of existing storm water detention ponds, channel stabilization to prevent erosion, and outreach to change pet waste management, lawn care, and other practices (U.S. EPA 2001a).

Manchester, New Hampshire

Large Surface Water System Where State Plays an Active Role

The City of Manchester gets its water from Lake Massabesic, which is located approximately three miles east of downtown Manchester. Management of the water supply is primarily under the jurisdiction of the Manchester Water Works. The lake has a surface area of about 2,500 acres and a gross storage capacity of nearly 15 billion gallons. For more than 120 years, this reservoir has served Manchester and five other communities. The Lake Massabesic water supply is supplemented by Tower Hill Pond, which has a gross storage capacity of 1.3 billion gallons. Manchester controls microbial pollution by restricting land use in the portions of the watershed controlled by the water works and the State.

The watershed area for the supply covers 42 square miles with over 25 percent owned and managed by the New Hampshire Department of Environmental Services (NHDES). The NHDES monitors these areas and controls recreational use through regulations posted in the surrounding area,

which are enforced by a staff of watershed patrol officers. These regulations strictly prohibit such activities as waste disposal, horseback riding, boating, or any other activity that would immediately or indirectly endanger the surface water quality. Other areas of the watershed are primarily monitored by the Manchester Water Works and have regulated levels of outdoor recreation. Activities such as mountain biking or the establishment of docks and moorings are subject to review and permitting by this agency. Parts of Lake Massabesic closest to the intake are closed to all activity.

The NHDES has provided funding to the Manchester Water Works for the protection of its watershed, specifically funding the installation of a storm water treatment facility and a project to address erosion and sedimentation. DES also provided funding for emergency planning, wellhead protection management plans, drainage mapping, storm water best management practices, and public outreach and education. The source of all this funding was the source water protection-related set-asides from the Drinking Water State Revolving Fund (U.S. EPA 2001b).

Springfield, Missouri Large GWUDI and Surface Water System with Rapidly Urbanizing Watershed

Springfield is a city of approximately 150,000 residents located in southwestern Missouri. Much of Springfield's bedrock is limestone and dolomite, and karst features are very pronounced. There are numerous losing streams, springs, and large concentrations of sinkholes in the area. The city's drinking water is provided by City Utilities of Springfield, a municipally-owned utility. The city uses a combination of springs, wells, reservoirs, and the James River to supply its daily demand of approximately 30 MGD.

The three primary threats to Springfield's water quality that have been identified by its watershed committee are: 1) urbanization in the watershed; 2) wastewater treatment in suburban and rural areas, which consists primarily of septic systems on karst terrain; and 3) agriculture, especially animal waste from concentrated beef and dairy cattle operations. Agricultural and urban BMPs are the primary methods used to address microbial contaminants.

In 1984 a citizen-based Watershed Management Coordinating Committee was established to guide and oversee water protection efforts. The group later incorporated as a non-profit organization and renamed itself the Watershed Committee of the Ozarks. The committee's operating budget is provided by Greene County (in which much of the watershed lies), the City of Springfield (containing the bulk of the water users), and City Utilities (U.S. EPA 2001c).

In 2001, the Committee hosted a workshop on conservation development and better site design for Springfield and Greene County planning and zoning staff members, hosted a workshop on agricultural best management practices (BMPs) for farmers, helped local developers incorporate stormwater BMPs and better site design into their developments, and helped local farmers install alternative watering facilities. The Committee currently has grants under Section 319 of the Clean

Water Act to restore several of the area's watersheds. One of these grants involves a study of the current and future loading rates of sediment and nutrients and future construction of a wetland or forebay to treat runoff from the Valley Water Mill watershed as it enters the reservoir. Another project for the Little Sac River Watershed, which provides 85 percent of Springfield's water, has just gotten underway (Watershed Committee of the Ozarks 2001).

2.2.2 What Are The Advantages and Disadvantages of a Watershed Control Program?

2.2.2.1 Advantages

Although the costs associated with implementing a particular toolbox option are system-specific, a watershed control program can cost less than options that require additional technology be installed. This is especially the case if other stakeholders contribute time and resources to the watershed control program. Stakeholders could include concerned citizens along with other municipalities, other agencies in the same municipality, and county or State employees. Watershed control programs that involve land acquisition or purchase of easements, however, may be as or more expensive than installing treatment.

Funding is available to implement many aspects of a watershed control program. For example, the Clean Water Act authorizes State revolving fund loans to upgrade wastewater treatment plants and provides grants (under Section 319) for control of nonpoint source pollution. The Farm Bill of 2002 authorizes several billion dollars for management of agricultural pollution. Drinking Water State Revolving Funds are also available to a limited extent for source water protection. Each State may set aside as much as 15 percent of its grant each year to provide loans for source water protection activities, including land or easement acquisition, implementation of incentive-based voluntary source water protection programs, and implementation of wellhead protection programs.

In addition, much of the information required to implement a watershed program, such as a contaminant source inventory and delineation of the watershed, will already be available as a result of the source water assessment conducted under the 1996 Safe Drinking Water Act Amendments. Section 1453 directs States to have completed source water assessments of PWSs by 2003. Although source water assessment programs vary from State to State, they will all provide much of the information required to implement a watershed program, allowing systems to incorporate existing information into their watershed control plans at minimal cost.

Flexibility is another advantage of a watershed control program. A watershed control program allows a system to design a suite of pollution management measures tailored to the physical, political, and economic characteristics of the local environment. This enables systems to focus resources on, and restrict costs to, actions that address the highest priority contaminants.

The reduction and prevention of source water contamination by microbial pathogens may also serve other public health and ecological goals, such as use of the water body for fishing and swimming, reduction of ground water contamination, and protection of aquatic habitats and the species that depend on such habitats for survival.

2.2.2.2 Disadvantages

There are some circumstances where a watershed control program may not be successful. Systems should consider the following potential pitfalls in deciding whether to adopt a watershed control program. Because *Cryptosporidium* occurs in low concentrations and is difficult to detect using existing analytical methods, it can be hard to determine whether concentrations have decreased as a result of a watershed control program. In addition, microbiological contaminants are frequently related to nonpoint sources, and control of these sources is often highly dependent on changing the behaviors of large groups of people. In a voluntary program (e.g., if the water system has no authority to regulate land use and is encouraging landowners to voluntarily take action), it is difficult to determine whether individuals are making the recommended changes necessary to control contaminants. Although the required annual watershed survey will assist in evaluating progress, systems that implement watershed control programs will need to be creative in finding ways to gauge the success of their programs.

A successful watershed control program requires the cooperation of a variety of stakeholders; however, it may be difficult to get agreement or participation from these stakeholders. Alternatively, stakeholder groups may agree to perform certain activities, such as outreach, but could lose funding and be unable to follow through on their commitments. Systems that have concerns about the likelihood of building strong relationships with their stakeholders may decide that a watershed control program is not appropriate for them. In some watersheds, depending on size of the watershed control program and the ability to share costs with others, significant PWS staff time may be required to oversee a program. These costs may be prohibitive for some systems.

Urban growth and land development can affect the success of a watershed control program. If growth occurs too quickly and there are insufficient controls on development, the subsequent decline in water quality can cancel out or even outstrip any improvement resulting from the watershed program. In high-growth areas, PWSs should make sure that the community is willing to support restrictions on development.

2.2.3 What If I Already Have a Watershed Control Program?

Systems that already have a watershed control program in place are permitted to choose this option; however, they will have to amend and strengthen their programs to get the log removal credit. This is because the credit, for all systems, is based on control measures that are *in addition* to the

program already in place. To get the additional credit, a system with an existing watershed control program could, for example, increase public outreach efforts or toughen land use ordinances that affect water quality. Systems with existing programs must still go through the entire application process.

2.3 How Do I Apply for Approval?

After notifying their States of their intention to participate, systems must include several items in their watershed control program plans. In addition to the plan itself, systems must submit a vulnerability analysis and an analysis of the interventions they considered in developing the plan. The procedure, based on the preamble to the LT2ESWTR, is provided below (U.S. EPA 2002a).

2.3.1 Notifying the State of Intention to Participate

Systems must notify their States of their intention to implement a watershed control program within one year of learning their initial bin assignment based on *Cryptosporidium* monitoring (40 CFR 141.725(a)(1)). The application and plan must be submitted for approval within two years after initial bin assignment (40 CFR 141.725(a)(2)).

2.3.2 Initial Approval of Watershed Control Program Plan

Initial State approval of a system's watershed control program will be based on State review of the system's proposed watershed control plan and supporting documentation, including a vulnerability analysis and analysis of the proposed control measures (40 CFR 141.725(a)(3)). The initial approval will be valid until the system completes the second round of *Cryptosporidium* monitoring (systems begin a second round of monitoring six years after the initial bin assignment) (40 CFR 141.725(a)(4)). At the very latest, systems must begin implementing the program 42 months (three and a half years) after the end of the source water monitoring period (40 CFR 141.701). The program elements are summarized below and described in more detail in section 2.4.

2.3.2.1 Vulnerability Analysis, Including Area of Influence

The application must include an analysis of the system's source water vulnerability to the different sources of *Cryptosporidium* identified in the watershed. The vulnerability analysis must characterize watershed hydrology and identify an "area of influence on source water quality" (the area to be considered in future watershed surveys). The analysis must also address sources of *Cryptosporidium*, seasonal variability, and the relative impact of the sources of *Cryptosporidium* on the system's source water quality (40 CFR 141.725(a)(3)(i)).

2.3.2.2 Analysis of Control Measures

The application must present an analysis of control measures that could address the sources of *Cryptosporidium* contamination identified in the vulnerability analysis. The analysis of control measures must discuss the effectiveness of each measure in reducing *Cryptosporidium* in source water (40 CFR 141.725(a)(3)(ii)).

2.3.2.3 Watershed Control Plan

The watershed control plan must be submitted within two years of initial bin assignment. It must address goals and define and prioritize specific actions to reduce source water *Cryptosporidium* levels. The plan must explain how actions are expected to contribute to specified goals; identify partners and their roles, resource requirements, and commitments; and include a schedule for plan implementation (40 CFR 141.725(a)(3)(iii)).

2.3.2.4 Approval and Conditional Approval

The State must review each system's proposed watershed control program plan and either approve, reject, or conditionally approve the plan. If the plan is approved, or if the system agrees to implementing the State's conditions for approval, the system will be awarded 0.5 log *Cryptosporidium* removal credit to apply toward additional treatment requirements.

2.3.3 Maintaining Approval of Watershed Control Program

Systems that have obtained State approval of their watershed control programs are required to meet the following additional requirements within each approval period to maintain compliance with their programs and continue their eligibility for the 0.5 log removal credit.

- Submit an annual watershed control program status report to the State during each year of the approval period (40 CFR 141.725(a)(4)(i)).
- Conduct an annual State-approved watershed sanitary survey and submit the survey report to the State (40 CFR 141.725(a)(4)(ii)).

The annual status reports, watershed control plan, and annual watershed sanitary surveys must be made available to the public upon request. These documents must be in plain language format and include criteria by which to evaluate the success of the program in achieving plan goals. The State may withhold portions of the annual status report, watershed control plan, and watershed sanitary survey based on security considerations (40 CFR 141.725(a)(4)(iii)).

The initial State approval of the system's watershed control program is valid until the system completes the required second round of *Cryptosporidium* monitoring (40 CFR 141.725(a)(4)). To be reapproved and to continue receiving 0.5 log treatment credit, the system must submit to the State an application for review and re-approval of the watershed control program six months before the initial approval period ends (40 CFR 141.725(a)(4)(iii)).

2.3.3.1 Submit Annual Status Report

The annual watershed control program status report must be submitted during the last three months of each year of the approval period, or by a date determined by the State. The report must describe the system's implementation of the approved plan and assess the adequacy of the plan for meeting the system's goals. It also must explain how the system is addressing any shortcomings in plan implementation, including those previously identified by the State or by the system during a watershed survey. If the system made any substantial changes to its approved program, it must describe the changes and explain the reason for making them. If the change is likely to reduce the level of source water protection, the system must explain what actions it will take to mitigate the effects (40 CFR 141.725(a)(4)(i)).

2.3.3.2 Conduct State-Approved Watershed Sanitary Survey

The State-approved watershed survey must be conducted annually according to State guidelines and by persons approved by the State to conduct watershed surveys. A report on the results of the survey must be submitted to the State annually. The survey must cover the area of the watershed that was identified in the approved watershed control program plan as the area of influence and must focus on assessing the priority activities identified in the plan and on identifying any significant new sources of *Cryptosporidium* (40 CFR 141.725(a)(4)(ii)). More information on watershed surveys is provided in section 2.5.2.

2.3.3.3 Request Review and Re-Approval

The system must request a review of its watershed control program by the State at least six months before the approval period expires or by a date previously determined by the State. The request must summarize activities and issues identified during the approval period and must include a revised plan that addresses activities for the next approval period. The revised plan must detail any proposed changes to the existing State-approved program. As with the initial request for State approval, the plan must address goals, prioritize specific actions intended to reduce source water *Cryptosporidium*, explain how these actions are expected to contribute to the achievement of goals, identify partners and their roles and resource requirements, and provide a schedule for plan implementation (40 CFR 141.725(a)(4)(iii)).

2.4 Developing the Watershed Control Program Plan

The following subsections discuss the factors systems should consider in determining the impact *Cryptosporidium* has on their water quality, along with descriptions of best management practices systems can use to protect their source water from *Cryptosporidium*.

2.4.1 Vulnerability Analysis

2.4.1.1 What Should Be Included in a Vulnerability Analysis?

The vulnerability analysis must address the vulnerability of each source to *Cryptosporidium* in the watershed upstream of the drinking water intake. It must include the following (40 CFR 141.725(a)(3)(i)):

- A characterization of the watershed hydrology
- Identification of an area of influence (the area to be considered in future watershed surveys) outside of which there is no significant probability of *Cryptosporidium* or fecal contamination affecting the drinking water intake
- Identification of potential and actual sources of *Cryptosporidium* contamination
- Determination of the relative impact of the sources of *Cryptosporidium* contamination on the system's source water quality
- An estimate of the seasonal variability of such contamination

Systems may be able to use the results of the source water assessments conducted under the Safe Drinking Water Act Amendments of 1996 in your vulnerability analysis. Most States will have completed source water assessments of surface water systems by the end of 2003. These assessments establish a foundation for the vulnerability analysis: they delineate the watershed, providing a starting point for defining the area of influence, and they inventory and rank the susceptibility of the water supply to actual and potential contamination sources. Some States involved PWSs in conducting source inventories and susceptibility analyses, so some PWSs may already have this information on hand. The assessments covered all contaminants in a watershed, including *Cryptosporidium* (U.S. EPA 1997). In some cases, if sufficiently detailed, the source water assessments may fully satisfy the analytical needs of the watershed control plan's vulnerability analysis.

Other source and watershed information may be available from sanitary surveys conducted for the IESWTR and the Long Term 1 Enhanced Surface Water Treatment Rule (these rules require sanitary surveys at least every three years for community water systems and at least every five years for noncommunity water systems). Guidance is available at <http://www.epa.gov/safewater/mdbp/pdf/sansurv/sansurv.pdf>. The California-Nevada section of the American Water Works Association and the California Department of Health Services Division of

Drinking Water and Environmental Management also have developed guidance specifically for watershed sanitary surveys.

2.4.1.2 How Should I Identify the Area of Influence?

The area of influence for which the vulnerability analysis is performed should be determined by several factors, including hydrology, location of *Cryptosporidium* sources, fate and transport, and pathogen loading . If watershed monitoring data are not available, it may be necessary to conduct some monitoring to determine the most problematic areas of the watershed.

In a small watershed, the geography and hydrology may not be important in determining the most sensitive areas, since the distance to the water source or streams feeding into the source is small. In such cases, all potential sources of *Cryptosporidium* contamination should be evaluated based on the characteristics of the source and the likelihood of *Cryptosporidium* release to a water body.

Delineation

As part of the source water assessments, States delineated the watershed surrounding each PWS's source. These delineations may be used as a starting point for determining the area of influence. To delineate watersheds, some States started with watersheds as catalogued by the U.S. Geological Survey (USGS) (Horsley and Witten 2001). The USGS has assigned each watershed and its subwatersheds in the United States a hydrologic unit code (HUC). Because the HUC subwatersheds can be quite large, and a PWS's source may come from only a section of the watershed, or portion of a hydrologic unit, sometimes only the part of the watershed upstream of the PWS's intake was mapped. Sometimes watersheds were further segmented into "critical areas" within which more detailed assessments were performed.

Some States delineated critical areas based on setbacks from the edge of the source water and all tributaries feeding into the source water. Others defined critical areas based on a fixed distance or time-of-travel from the intake (upstream of the intake or in all directions from the intake) (Horsley and Witten 2001).

Systems that need to delineate their watersheds or subwatersheds for the first time and do not have geographical information system (GIS) available can do so easily with topographic maps. The first step is to find the source (including tributaries) and the water treatment plant intake on the map. Each of the contour lines (which is actually not a line but a closed shape) around the source connects points of equal elevation. Upstream, the elevation indicated by each contour line increases with distance from the source. All precipitation falling within a zone of increasing elevation around the source will flow towards the source. Where the contour elevations stop increasing and begin decreasing is the break point. On the other side of the break point, water is flowing into a different watershed. The area delineated by connecting the break points is the watershed (AWWA 1999). See

<http://www.terrene.org/fl16.pdf> for an illustrated fact sheet on delineation. If the intake is not at the downstream end of the watershed, it is only necessary to delineate the area upstream of the intake.

Systems with GIS can follow the same process using digital elevation model (DEM) data rather than contour lines.

Within the watershed, systems may wish to delineate the area of concern based on fixed distances from the shore of the source or based on time of travel (see box).

PWSs using ground water under the direct influence of surface water (GWUDI) as a source can delineate an area of influence by combining a delineation of the watershed influencing the ground water source with a delineation of the wellhead protection area.

Watershed Hydrology

Once the watershed has been delineated, PWSs should examine the hydrology of their watersheds to help determine the area of influence. The vulnerability analysis submitted to the State must contain information on the watershed's hydrology.

Stream discharge can affect the transport of sediment and *Cryptosporidium* oocysts, especially during and after storms.

When more rain falls than can be absorbed immediately by the soil, soil cover, or impervious surface, water will pond on the surface. With increasing rainfall, the water will flow to a lower level on the surface, to a river, lake, or reservoir, as shown in Exhibit 2.1. As water travels, it may pick up contaminants on the soil surface (e.g., *Cryptosporidium* oocysts from deposited fecal matter). These particles are then suspended in the runoff and can be transported to surface water supplies. The microorganisms (including parasitic protozoa)

Delineation Based on Travel Time

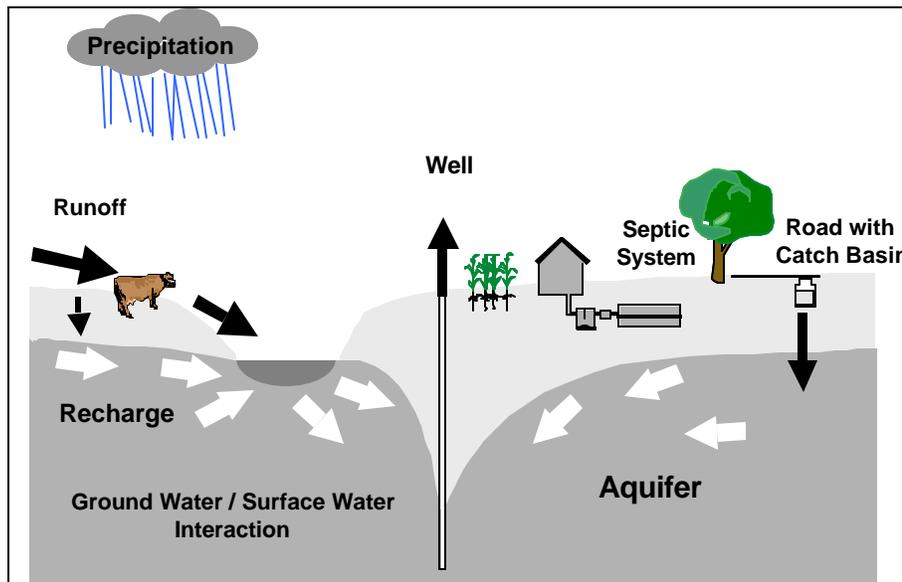
In its watershed control program, the New York City Department of Environmental Protection delineated an area around its reservoirs that has a 60-day residence time 95 percent of the time (Klett 1996). Within this zone, the department limits the operation and construction of wastewater treatment plants. The residence time was calculated using the formula $T=V/Q$, where T =time, V =volume of the reservoir, and Q =flow out of the reservoir. Determining residence time experimentally would have been too time-consuming and expensive.

The department adjusted the actual reservoir volume in its calculations to reflect changes over time. First, it accounted for de facto changes in volume resulting from stratification (i.e., during the summer there is little vertical mixing, so the volume of the bottom layer of the reservoir never enters into the $T=V/Q$ equation). Where the entrance to an aqueduct transporting water from a reservoir was significantly upgradient of the reservoir dam, the volume of the water downgradient of the aqueduct also was subtracted, because water moving through the reservoir may enter the aqueduct without ever reaching the downgradient area. The department also adjusted for changing reservoir volumes caused by rising and falling water levels.

If the calculated residence time of a reservoir close to New York City was less than 60 days, the residence time of the next upstream reservoir was added. Once a 60-day time was achieved, the watershed around each of the reservoirs (or parts of the reservoirs) was delineated based on surrounding topography.

associated with the soil can be transported as individual organisms, aggregates of organisms, or within an aggregate of soil particles and organisms.

Exhibit 2-1. Ground Water/Surface Water Interaction



Ground water that is considered to be under the direct influence of surface water (GWUDI) is usually immediately adjacent to surface water or to the discharge point of a spring. These ground water supplies are considered especially vulnerable to contamination by parasitic protozoa. GWUDI may be contaminated by direct infiltration of oocysts from the surface as a result of rain, but, more commonly, ground water is contaminated as a result of the action of pumping wells (see Exhibit 2-1). Given sufficiently high pumping rates, wells can locally reverse the direction of ground water flow. In such cases, surface water is induced to flow from a river, lake, or reservoir into the adjacent ground water, where it may be extracted by one or more pumping wells. If the surface water is contaminated with oocysts, the adjacent ground water may also become contaminated.

Water quality flow models analyze specific hydrologic, geographic, and water quality parameters to estimate the travel time needed for contaminants to reach a drinking water intake and the amount of contamination at that intake. Surface runoff models may also be used to assess the potential impact of individual *Cryptosporidium* sources, and to identify watershed areas with the greatest potential impact on source water quality. Models should always be validated for the settings in which they are used.

PWSs should also consider topography and soil type, which can affect hydrology. Areas with steep slopes may experience a higher percentage of overland flow or runoff (as opposed to infiltration and subsurface flow) and have faster overland flow rates during rainfall than flat areas.

Cryptosporidium may be more likely to be transported to water bodies in such areas, although if the topography is very steep, livestock that carry *Cryptosporidium* may not be present. Impermeable or compacted soil, impervious surfaces, unvegetated areas, and a high water table can also affect overland flow. Riparian zones can be considered sensitive areas simply due to their proximity to streams that feed into source waters. They are also subject to erosion. PWSs should also factor soil types into their decisions; areas with high clay content may be more impermeable or more subject to erosion and can contribute to high turbidity.

2.4.1.3 What and Where Are the Potential or Existing Sources of *Cryptosporidium*?

All *Cryptosporidium* sources must be reported in the vulnerability analysis (40 CFR 141.725(a)(3)(i)). Systems may be able to use source inventory data collected as part of the source water assessment program. Most States are asking systems to assist with identifying significant potential contaminant sources (Horsley and Witten 2001), either through field verification or through review of inventory databases or other information. Therefore, some PWSs should already have this information available. States will also be assessing the risk of each source or category of sources, primarily through numerical ranking systems and matrices; systems will have this information at their disposal as well. It is possible that the inventory and ranking of potential sources may not be detailed enough for a *Cryptosporidium* watershed control program, but they should provide a good starting point.

After noting sensitive areas based on topography and geology, systems should determine whether these areas coincide with land use that could contribute to microbiological contamination. Reviewing land use and zoning maps helps target areas for further investigation or for prediction of future sources and loading. PWSs should then search local data sources, such as health department data on septic systems, and review recent sanitary survey results. Furthermore, they should obtain data on point sources such as wastewater treatment plants that require EPA or State permits, e.g., National Pollutant Discharge Elimination System (NPDES). NPDES information (also called water discharge permit or PCS data) is available on EPA's Envirofacts website at http://www.epa.gov/enviro/index_java.html. After identifying potential sources of contaminants, systems should field verify the locations of these point and nonpoint sources.

The paragraphs below summarize existing research on *Cryptosporidium* sources and associated land use in watersheds. Because most studies of *Cryptosporidium* occurrence involve sampling at water system intakes, little information is available about occurrence of *Cryptosporidium* within watersheds and transport of oocysts to surface water supplies. The studies described are site-specific; it is important to investigate these relationships in one's own watershed as well.

Land Use

The character (topography, plant cover) and land uses (urban, farming) within a watershed also influence the occurrence or concentration of *Cryptosporidium* in surface water (Hansen and Ongerth 1991). Oocyst concentrations can be as much as 10 times higher in urban and agricultural watersheds (Hansen and Ongerth 1991, Stern 1996) than in undeveloped ones. However, such differences may be site-specific—in streams in an agricultural watershed in southern Ontario, no connection was found between *Cryptosporidium* concentration and sources or land use such as wastewater treatment plants, combined sewer overflows, livestock, crops, houses, wildlife, and campgrounds (Fleming et al. 1999).

Sources

Many land uses in a watershed have the potential to introduce *Cryptosporidium* into water supplies. These include point sources—combined sewer overflows, wastewater treatment plants, and concentrated animal feeding operations—and nonpoint sources, including livestock, wildlife, pets, storm water runoff, and septic systems. Seasonal variations in precipitation may affect *Cryptosporidium* concentrations as well. Point and nonpoint sources of *Cryptosporidium* are described below.

Point Sources

Point sources such as combined sewer overflow (CSO) outfalls, which are common in older municipalities, can be a significant source of oocysts, depending on the weather and the endemic rate of cryptosporidiosis. CSOs contain raw sewage diluted by storm water. In one study, *Cryptosporidium* concentrations at CSO outfalls on the Allegheny River in Pittsburgh during storms ranged from 0 to 3,000 oocysts/100 L, with a geometric mean of 2,013 oocysts/100 L (States et al. 1997).

Wastewater treatment plants may also contribute to oocyst loads, depending on the amount of treatment provided. Primary treatment can remove as little as 27 percent of oocysts from effluent (Payment et al. 2001); most plants in the United States provide secondary treatment, so removal should be better. In the Netherlands, it is estimated that 85 percent of *Cryptosporidium* oocysts occurring in surface water are discharged in wastewater treatment plant effluent (Medema and Schijven 2001). In one study in Pittsburgh, oocysts were detected in 33 percent of samples with a geometric mean concentration of 924 oocysts/100 L over 24 months of sampling (States et al. 1997). In another study near Philadelphia, concentrations ranged from 33 to 2,490 oocysts per 100 L (67 percent of samples were positive); downstream from the plant, concentrations ranged from 325 to 825 oocysts per liter (Crockett and Haas 1997).

Concentrated animal feeding operations (CAFOs) can be a significant source of animal waste, which can contaminate source water in two ways. If not properly managed, waste can leak or

overflow from waste storage lagoons, feedlots, or other facilities. In addition, waste applied as fertilizer to fields can run off into drinking water sources or source tributaries, especially if overapplied.

Nonpoint Sources

Agriculture can also be a nonpoint source of *Cryptosporidium*. On a stream running through a small dairy farm before feeding into the Allegheny River, *Cryptosporidium* was detected in 82 percent of samples (States et al. 1997), with a geometric mean concentration of 42 oocysts/100 L. Twice during the 24-month study, concentrations of more than 1,000 oocysts/100 L were observed. In an agricultural area in Canada, drain tiles contained average concentrations of 771 oocysts/100 L. Concentrations were high even in tiles on farms without barns (these farms were assumed not to have livestock present). Oocysts were also present in some samples in liquid swine manure storage lagoons (Fleming et al. 1999).

Cattle are thought to be significant sources of oocysts. *Cryptosporidium* infection rates in cattle depend on animal age. Calves, particularly those less than one or two months old, have the highest rates (infection rates in different studies range from 2 to 39 percent of calves) (Wade et al. 2000, Sicho et al. 2000, Huetink et al. 2001).

Cryptosporidium may directly enter surface water via waterfowl. Oocysts have been found in Canada goose feces collected in the environment (Graczyk et al. 1998). Canada geese, some of which no longer migrate, could cause considerable contamination of surface water sources and uncovered finished water reservoirs.

Other wildlife may also be a source of *Cryptosporidium*, though the impact on source water may not be as direct. Deer, muskrat, and other small mammals were shown to carry *Cryptosporidium* in upstate New York (Perz and Le Blancq 2001). In one study of California ground squirrels, 16 percent of squirrels sampled were found to shed an average of 50,000 oocysts per gram of feces (Atwill et al. 2001). The infection rate in each species and the species present in each watershed will vary, so the contribution from wildlife will also differ from watershed to watershed.

Although little research has been performed on the overall prevalence of *Cryptosporidium* in pets, *Cryptosporidium* has been detected in dogs and cats, although pets usually carry strains that are rarely detected in humans. Several studies have shown dogs to be significant carriers of *Giardia*, fecal coliform, and other bacteria (Schueler 1999), and these microbes have been found in storm water, suggesting that *Cryptosporidium* may also be present in urban watersheds and stormwater runoff.

Low levels of *Cryptosporidium* may also enter surface water through septic systems and subsequent subsurface transport (Lipp et al. 2001).

Cryptosporidium sources can be identified through polymerase chain reaction (PCR) analysis of *Cryptosporidium* DNA. PCR can be used to determine the species or genotype of *Cryptosporidium*; many genotypes or species are typically, although not exclusively, found in specific hosts, such as cattle, dogs, and humans. In mixed-use watersheds, this information can help determine whether *Cryptosporidium* in the source water could have come from agricultural runoff, combined sewer overflows, or stormwater runoff.

Influence of Precipitation

Systems should determine the extent to which *Cryptosporidium* occurrence in their watershed coincides with extreme rainfall—68 percent of waterborne disease outbreaks between 1948 and 1994 were shown to be associated with heavy precipitation (Curriero et al. 2001). *Cryptosporidium* occurrence may also be related to seasonal variations in infection among livestock, but any correlation is site-specific and depends on the source. In a study in six watersheds, Sobrinho et al. (2001) found no substantial difference between *Cryptosporidium* detection rates during “event” (rainfall, high turbidity, melting snow and spring runoff) and “non-event” sampling when all data were taken together. However, for three of the watersheds, when examined individually, detection within each watershed was significantly higher during event sampling.

Both *Cryptosporidium* detection and concentrations at six watersheds were highest between the months of October and April, with March experiencing a detection rate of more than 30 percent and oocyst concentration of about 0.038 oocysts/L (Sobrinho et al. 2001).

Other studies have noted a connection between rainfall and “extreme runoff” events in tributaries to drinking water sources (Kistemann et al. 2002). One study noted a *decrease* in farm stream concentrations of *Cryptosporidium* with an increase in 5-day cumulative precipitation (probably because continued rainfall washed most of the *Cryptosporidium* downstream) (Sischo et al. 2000).

2.4.1.4 How Do Fate and Transport Affect the Way *Cryptosporidium* Impacts My Water Supply?

Transport of oocysts in surface water and ground water and survival of oocysts all affect the potential impact of *Cryptosporidium* on water supplies. The behavior of oocysts in each medium is described below.

Transport in Surface Water

The buoyancy of oocysts in water depends on their attachment to other particles. Oocysts that are not bound to particles have a tendency to float, even after being centrifuged (Swabby-Cahill et al. 1996). *Cryptosporidium* oocysts have a very low density (about 1.05 g/cm³) and a very low settling

rate (2 mm per hour or less), which suggests that sedimentation without coagulation may not be an effective means of oocyst removal (Gregory 1994). Oocysts attached to wastewater effluent particles may settle more quickly than those that are freely suspended and sedimentation velocity increases with particle size (Medema et al. 1998). In source waters, many oocysts are likely to be adsorbed to organic or other suspended material and would probably settle more quickly than free-floating oocysts (Medema et al. 1998).

Cryptosporidium is thought to be easily transported over land. Because oocysts are approximately the size of clay/silt particles, the amount of kinetic energy needed to entrain and suspend oocysts in overland flow may be quite small (Walker et al. 1998).

Transport in Ground Water

Surface water sediments and the aquifer matrix material may play significant roles in minimizing oocyst transport to water supply wells; however, it is difficult to isolate the effect of these materials on transport. For example, if oocysts are not detected in a sample, it could be because they are not present in the aquifer or that they are present but were not recovered in the laboratory. Or it could be that fractures or dissolution conduits in the aquifer allow ground water and oocysts to effectively bypass the protective action of most of the aquifer matrix.

It is known that *Cryptosporidium* can be transported through soil and ground water (Mawdsley et al. 1996; Hurst 1997). For instance, in one study examining riverbank filtration, oocysts were recovered at a well 200 feet from the Ohio River (Arora et al. 2000). Movement of *C. parvum* through soil and ground water is affected by sedimentation and filtration of the surrounding soil and aquifer matrix (Brush et al. 1999; Harter et al. 2000). Adsorption of oocysts to matrix particles also affects filtration. Adsorption depends on the electrical charge of the organism and of the surrounding matrix. A charge on the oocyst can change the effective diameter of the oocyst; however, the charge is difficult to ascertain because it can be altered by the purification method used to recover oocysts in the laboratory (Brush et al. 1998).

Factors other than adsorption and micropore size may influence the oocyst movement. *C. parvum* transport in one study was greater in a silty loam and a clay loam soil than in a loamy sand soil (Mawdsley et al. 1996); this contradicts other evidence suggesting that clay soils exhibit greater adsorption and smaller micropores than sandy soils. The authors used intact soil cores (rather than columns created in the laboratory) to maintain the natural soil structure and macropores, and they concluded that the rapid flow of water through macropores largely bypasses the filtering and adsorptive effects of the soil and increases the risk of *Cryptosporidium* transport to ground water (Mawdsley et al. 1996).

Survival in the Environment

Several factors influence oocyst survival. This section presents the findings from several studies describing oocyst inactivation due to temperature and desiccation.

Before oocysts enter a water source, they may be vulnerable to desiccation. Robertson et al. (1992) reported that air drying an oocyst suspension at room temperature for 4 hours eliminated viability. Oocysts in fecal material, however, are protected from desiccation, so their viability in the environment is prolonged (Rose 1997). In addition, *Cryptosporidium* in liquid swine manure has been shown to remain viable despite the high ammonia content of the manure (Fleming et al. 1999). However, Olson et al. (1999) found that oocyst survival appears to be better in soil than in feces.

Once initial contamination has occurred, water can remain a source of viable oocysts for days (Heisz 1997; Lisle and Rose 1995). Lisle and Rose reported a duration of 176 days to produce die-off rates of 96 percent in tap water and 94 percent in river water under laboratory conditions. After 2 days, only 37 percent of the oocysts in tap water were nonviable, suggesting that oocysts that reach the distribution system might be viable.

Olson et al. (1999) compared oocyst survival at temperatures and in media likely to occur in the natural environment. They examined survival in -4°, 4°, and 25° C. Unlike *Giardia*, which died off quickly at low temperatures, *Cryptosporidium* oocyst survival was best at -4°C, with close to 50 percent of oocysts remaining viable for 12 weeks. Survival was lowest at 25°C, but oocysts were still viable at six weeks. Survival rates were best in water and worst in feces.

Loading

Once you have gathered information about *Cryptosporidium* sources and the likelihood of the oocysts reaching your source water (based on watershed characteristics and fate and transport), you should determine the amount and proportion of oocysts that each source is expected to contribute to the overall *Cryptosporidium* load. Loading can be calculated fairly easily for constant point sources such as wastewater treatment plants but is more difficult for farms and urban runoff; monitoring and water quality modeling may be necessary (see section below on monitoring).

2.4.1.5 What Role Should Monitoring Play in a Vulnerability Analysis?

The vulnerability analysis is required to address sources of *Cryptosporidium*, seasonal variability, and the relative impact of the sources of *Cryptosporidium* on a system's source water quality (40 CFR 141.725(a)(3)(i)). While you may already have some knowledge of potential *Cryptosporidium* sources through land use information or discharge permit data, monitoring can help you determine the extent to which these sources are impacting your source and can help you target portions of your watershed for extra protection or BMP implementation. Although not required as part of the vulnerability analysis, monitoring throughout your watershed for *Cryptosporidium* (or indicators of fecal contamination) is the best way to measure the success of a watershed control program.

Monitoring data collected during the vulnerability analysis provide a baseline against which you can compare data gathered during implementation of the watershed program. Some PWSs, as well as the USGS and local universities, may already have some water quality or streamflow data available.

Watershed monitoring can help narrow down the locations of some sources and determine the load contributed by each source. The Philadelphia Water Department, for example, planned a four-tier study to determine why there was such a large difference in protozoan levels at two plants using the same source (the Schuylkill River) but located 2.5 miles apart (Crockett and Haas 1997) (see sidebar).

Because *Cryptosporidium* occur in low concentrations and are difficult to detect, it may be helpful to monitor other parameters in addition to or instead of *Cryptosporidium*. While *E. coli* concentrations often do not correlate with *Cryptosporidium* levels, they are good indicators of fecal contamination. Fecal coliform bacteria have traditionally used as water quality indicators, but *E. coli* is thought to be more closely linked to fecal contamination. Turbidity does not always indicate fecal contamination; often, increased turbidity is simply a product of high sediment levels. However, turbidity may indicate the presence of a water quality problem, where additional research is necessary to determine its cause.

Monitoring should be conducted regularly. Because nonpoint sources of microbiological contamination discharge primarily during wet weather flows, monitoring during or soon after these events is also important. When combined with stream discharge data, rates of storm-related *Cryptosporidium* transport and loading can be calculated. The monitoring frequency should be such that seasonal variability in *Cryptosporidium* levels is observable.

Monitoring to Locate *Cryptosporidium* Sources

To determine the source of *Cryptosporidium* contamination in the Schuylkill River, the Philadelphia Water Department decided to focus on a creek feeding into the Schuylkill just before the Queen Lane plant (Crockett and Haas 1997). This creek has several wastewater treatment plants in its upper reach and farms and parks along its lower reach. In the first phase, the water department tested the Queen Lane intake during dry flow. It then sampled a site along the creek downstream of the wastewater treatment plants and one downstream of the farms during various weather conditions. In the third tier of sampling, the department sampled wastewater effluent and additional sites up- and downstream of some of the wastewater treatment plants during different weather events. Lastly, the department planned to focus on the prevalence of *Cryptosporidium* and *Giardia* in livestock and wildlife along the creek. Results are discussed in section 2.4.1.3.

There are two types of watershed monitoring for stream networks. First, basinwide monitoring involves monitoring just upstream of the confluence of two streams (AWWARF 1991). Conducted at stream junctions throughout the watershed, basinwide monitoring helps give a general picture of the

water quality and helps isolate the stream reaches contributing to contamination. Second, site-specific monitoring involves monitoring just upstream and downstream of a suspected or known point or nonpoint source, as the Philadelphia Water Department did (Crockett and Haas 1997). Such monitoring is appropriate where impacted stream reaches have already been identified. The results of any monitoring should enable the system to compare the relative contribution of various sources to the overall *Cryptosporidium* occurrence in the watershed and their effect on water quality.

Monitoring in a reservoir or lake, if applicable, can help systems determine the fate of *Cryptosporidium* once it flows from a stream into the lake, or once it enters the lake directly from land immediately adjacent to the lake. Sampling patterns should depend on the shape and depth of the lake. A round lake should be sampled at several locations and depths near the center of the lake; a long lake should be sampled in a transect along its long axis (AWWARF 1991). More specific monitoring may be needed to answer more detailed questions on fate and transport. For instance, does *Cryptosporidium* concentration decrease due to sedimentation or dilution? How long does it take for *Cryptosporidium* to flow from one end of the reservoir to the intake?

PWSs may find it helpful to use a geographic information system (GIS) to analyze their water quality and contaminant source data. For systems that have ArcView software, BASINS 3.0, a software and GIS package developed by EPA, can assist systems with integrating local data and nationally available pre-formatted spatial data (e.g., watershed hydrologic unit codes (HUCs), digital elevation model (DEM) data, roads, NPDES permit data, and Clean Water Needs Survey data on wastewater treatment plants). BASINS also includes a model for determining nonpoint source loading and other models for loading and transport, as well as tools for assessing contamination from various sources.

2.4.2 Analysis of Control Measures

The analysis of control measures submitted with the watershed control plan must address the relative effectiveness of each measure at reducing *Cryptosporidium* loading to the source water, along with the sustainability of each measure (40 CFR 141.725(a)(3)(ii)).

Control measures may include 1) the elimination, reduction, or treatment of wastewater or storm water discharges, 2) treatment of *Cryptosporidium* contamination at the sites of the waste generation or storage, 3) prevention of *Cryptosporidium* migration from sources, or 4) any other measures that are effective, sustainable, and likely to reduce *Cryptosporidium* contamination of source water. If you do not own or otherwise have authority over the *Cryptosporidium* sources in your watershed, you may need to develop and maintain partnerships with landowners within the watersheds. These could include other municipal governments, farmers, wastewater treatment plant operators, regional planning agencies, and others. Examples of these partnerships and possible control measures for different sources are described in the following sections; further detail is provided in Appendix E.

2.4.2.1 How Should I Build Partnerships with Other Stakeholders?

Many watershed management practices cannot be implemented by water systems alone. For example, agricultural BMPs must be implemented by farmers; stormwater BMPs are implemented by developers, manufacturers, and government agencies. Parts of your watershed may be in different municipalities. Therefore, it is imperative that PWSs work with these and other stakeholders to solicit their input and earn their cooperation.

The type of partnership you build depends on each type of stakeholder. With government agencies you might need to sign memoranda of agreement or make other formalized arrangements. For some types of stakeholders it may be more appropriate or efficient to reach out to technical assistance providers such as cooperative extension agents or association representatives and provide them with information to distribute. Ultimately, however, you must reach out to individual stakeholders, because people who don't know about the watershed control program will not be as likely to do their part.

Increasingly, PWSs are incorporating more intensive stakeholder participation into their planning whenever possible. They have found that dialogue with stakeholders is more likely to result in an acceptable solution than situations in which systems simply inform stakeholders that they already know the best way to address a problem (AWWARF 2001). The book *Guidance to Utilities on Building Alliances with Watershed Stakeholders* (AWWARF 2001) explains how to present issues to stakeholders, how to target stakeholders, and how to structure your partnership with stakeholders.

2.4.2.2 What Regulatory and Other Management Strategies Are Available to Me?

For systems in watersheds where most of the land is privately owned, land use regulations may be the best way to control pollution, especially in heavily developed or growing areas. Examples of possible regulations include septic system requirements, zoning ordinances specifying minimum lot sizes or low-impact development, limits on discharge from wastewater treatment plants and other facilities, pet waste cleanup ordinances, and requirements for permits for certain land uses. Your ability to regulate land use will depend on the authority granted to your municipality by the State, the ownership of your system (public or private), and the support of your local government and the public. Regulatory authority, steps for designing a regulation that can withstand lawsuits, and types of land use regulations are described in the paragraphs below.

Determining Authority to Regulate

The ability of a municipality to pass a land use ordinance or other law to help reduce contamination may depend on the authority the State grants to the local government in the State constitution or through legislation, although States normally do not interfere with the actual land use and zoning rules (AWWARF 1991). Privately owned water systems may need to ask the cooperation of the local government to get source water regulations passed. Publicly owned PWSs face less of a hurdle, although winning support of the local government may still be difficult.

If the area of influence on water quality extends throughout several municipalities, it can be difficult to standardize watershed control practices throughout the watershed. The legal framework used will depend on who has jurisdiction over land use in the watershed and on the authority of the water system (AWWARF 1991). For example, some States may create agencies authorized to promulgate and enforce watershed protection regulations, or interstate agencies may be created to regulate watersheds where watersheds cross State boundaries. County governments in some States may have some zoning authority and may be able to assist with enforcement of some regulations affecting source water (e.g., septic systems).

Where PWSs do not have regulatory or enforcement authority, they should work with other local governments' PWSs and agencies in their watersheds to sign memoranda of agreement or understanding, in which each entity agrees to meet certain standards or implement certain practices.

Zoning

Early zoning laws simply prohibited certain land uses that would be considered nuisances in certain areas. Later, zoning ordinances became more specific; further restrictions were imposed on the permitted uses, such as limits on building or population density, percentage of impervious surface area, building height, and minimum distance of buildings from property boundaries. Most zoning ordinances have grandfather clauses that allow nonconforming uses to continue. Ordinances may also allow the zoning authority to grant variances if the topography or size of a lot make it difficult to comply with a zoning requirement.

To make sure a zoning law can withstand a legal challenge, it is important to make sure the appropriate procedures are followed and that the law has sufficient scientific basis (AWWA 1999). First, be sure you have the authority to regulate. Make sure the rule is specific enough. Comply with all administrative procedure requirements; failure to do so is the most common reason for rules being revoked. The ordinance should conform to the objectives of the watershed control program plan, which should contain enough data to illustrate how the ordinance will affect water quality.

Ordinances should also be designed to withstand a takings lawsuit (AWWA 1999). The fifth amendment to the U.S. Constitution states that private property may not be taken for public use without

just compensation. Any physical invasion without consent is always considered a taking, even if the landowner retains ownership of the land. Installation of a monitoring well or stream gauge without consent is an example of a taking.

To prevent takings claims, the municipality should show the need for the regulation and a connection between the ordinance and the expected result (AWWA 1999). This proof should be based on a scientific analysis beginning with an accurate delineation of the watershed or wellhead protection area/recharge area.

Following the delineation, determine the impact the regulation will have by mapping current and projected development under current zoning requirements. Then map current and projected development for the proposed ordinance and determine the potential pollutant load under each scenario (AWWA 1999). Local groups or universities may be able to provide pollutant data and assist with modeling. This “buildout analysis” will help you show that your proposed ordinance advances a legitimate government interest and how the effect of the ordinance is proportional to the impact of land use in your watershed.

Types of Ordinances

Watershed ordinances usually apply within an “overlay district,” which may be the area of influence you determined for your watershed control plan. All existing zoning or land use regulations apply within that area, but additional requirements apply within the overlay district. Within your watershed, particularly within the area of influence, there are many different kinds of regulatory controls you may wish to consider:

- Large-lot or low-density zoning.
- Limits on certain types of land use except by special permit.
- Impact fees.
- Submission and approval of a watershed protection plan or impact study as a condition for development of a subdivision or apartment complex.
- Performance standards, which permit development but limit the impact of the development.

More detail on each of these types of ordinances is found in Appendix E. Examples of source water protection ordinances can be found on EPA’s website at <http://www.epa.gov/owow/nps/ordinance/osm7.htm>.

Land Acquisition/Conservation Easements

Acquisition of watershed land by the utility or its affiliated jurisdiction is often the most effective approach to protecting the water source. EPA’s Drinking Water State Revolving Fund allows a percentage of the fund to be set aside for land acquisition associated with watershed protection.

Land trusts and conservancies can help systems purchase land to protect drinking water quality, especially when government agencies are unable to move quickly enough to buy land when it becomes available. Trusts can buy and hold land from multiple landowners on behalf of a water system until the system can assemble funding to purchase it from the trust. The Trust for Public Land (<http://www.tpl.org>) can provide more information.

Trusts also can work with landowners to buy or have landowners donate conservation easements. An easement is a legal document that permanently limits the development of a piece of land, even after the land is sold or otherwise changes ownership. See <http://www.landtrust.org/ProtectingLand/EasementInfo.htm> for frequently asked questions about easements and for an example of a model easement for use in the State of Michigan. The Land Trust Alliance (<http://www.lta.org>), a trade organization for land trusts, has published handbooks on designing and managing conservation easement programs.

Other government agencies, such as the U.S. Forest Service or State natural resource departments, may be able to buy parcels in your watershed if you are unable to afford to purchase all the land that needs to be protected.

2.4.2.3 How Should Point Sources Be Addressed?

Changes in farming practices and in wastewater treatment technologies in the past decade have resulted in new management strategies for agricultural and urban point sources. The following sections briefly describe solutions for agricultural, wastewater, and stormwater point sources; detailed descriptions are provided in Appendix E. As part of your application for watershed control program approval, you must submit an analysis of control measures that can mitigate sources of *Cryptosporidium* such as these (40 CFR 141.725(a)(3)(ii)). Loans from the Clean Water State Revolving Fund can be used to fund projects associated with wastewater treatment and watershed and estuary management. See www.epa.gov/owm/cwfinance/cwsrf/index.htm for more information.

- ***Concentrated Animal Feeding Operations***

Animal feeding operations (AFOs) are facilities where animals are confined for 45 days or more a year and where no vegetation grows in the area used for confinement. This includes farms where animals graze the majority of the year but are confined and fed during the winter for at least 45 days. Some AFOs are also considered concentrated animal feeding operations (CAFOs) (see Appendix E). EPA recently issued a rule that changed the requirements on CAFOs that must apply for National (or State) Pollutant Discharge Elimination System (NPDES) permits (U.S. EPA 2003). The new CAFO rule requires CAFOs to implement nutrient management plans that affect manure handling, storage, and land application. These plans will include best management practices (BMPs) primarily designed to reduce nitrate and phosphorus contamination but which will at the same time reduce pathogen contamination. Elements of this plan may include limiting the manure land application rate,

instituting buffer zones where manure is applied, ensuring adequate manure and wastewater storage, and others.

- **Wastewater Treatment Plants**

All wastewater treatment plants in the United States are required to provide secondary treatment (U.S. EPA 2001e). Most plants are also required to disinfect their effluent before discharging. However, conventional chlorine disinfection in wastewater plants is ineffective against *Cryptosporidium*. Some wastewater treatment facilities are beginning to implement treatment similar to that used for drinking water treatment (e.g., advanced treatment, including chlorine disinfection, filtration, and dechlorination). PWSs should identify all wastewater treatment plants in their watersheds and determine what their permit effluent limits are and whether the limits are being met.

- **Combined Sewer Overflows**

Combined sewers carry both sewage and storm water to wastewater treatment plants. During storms, the volume of water in combined sewers may become too great for wastewater plants to treat. As a result, the excess sewage and storm water are released untreated into surface water through CSOs. CSOs are most common in older cities in the northeastern and midwestern United States and can be a significant contributor of *Cryptosporidium* to urban watersheds.

There are three major structural solutions to the problem of CSOs:

- Separate combined sewers into sanitary and storm sewers, where sanitary sewers flow to the wastewater treatment plant and storm sewers release to surface water.
- Increase the capacity of the wastewater treatment plant so that it is able to treat combined sewage from most storms.
- Build aboveground covered retention basins or to construct underground storage facilities for combined sewage to hold the sewage until the storm has passed and can be treated without overloading the plant.

Although CSOs are not regulated directly under their own program, EPA has a CSO control policy (U.S. EPA 1994) which encourages minor improvements to optimize CSO operation, and CSO management may be written into NPDES or State Pollution Discharge Elimination System (SPDES) permits. Minor improvements include maximizing in-line storage within the sewer system, reducing inflow, and treatment of CSO outfalls.

- **Sanitary Sewer Overflows**

Watersheds with separate sanitary and storm sewer systems may still have water quality problems. Sanitary sewer overflows (SSOs) occur when untreated and mostly undiluted sewage backs up into basements, streets, and surface water. SSOs discharging to surface water are prohibited under

the Clean Water Act. Insufficient maintenance and capacity and illegal connections are some of the primary causes of SSOs.

SSOs can be reduced by cleaning and maintaining the sewer system; reducing inflow and infiltration by repairing leaking or broken service lines; increasing sewer, pumping, and/or wastewater treatment plant capacity; and constructing storage for excess wastewater (U.S. EPA 2001f). EPA is proposing a rule that will require sewer systems to implement capacity assurance, management, operation, and maintenance programs and will require public notification of overflow events. This information will assist PWSs in addressing SSO point sources.

- ***Municipal Separate Storm Sewer Systems***

Municipal separate storm sewer systems (MS4s) in areas with populations of more than 100,000 are also required to obtain NPDES permits. Information on storm sewer outfall locations, volume discharged, conventional pollutant loads, and existence of illicit discharges is submitted as part of the permit application process (U.S. EPA 1996). In addition, these MS4s must develop management plans addressing items such as outfall monitoring, structural and nonstructural BMPs to be implemented, and identification and elimination of illicit discharges. Illicit discharges to MS4s include any non-stormwater discharges, such as discharges that should be connected to sanitary sewers (e.g., water from sinks, floor drains, and occasionally toilets), illegal dumping of sewage from recreational vehicles, sanitary sewer overflow backing up through manhole covers into storm drains, effluent from failing septic systems, water from sump pumps, etc.

Small MS4s (serving areas with populations of less than 100,000), with some exceptions, are subject to NPDES permit requirements if they are located in “urbanized areas” as determined by the Bureau of the Census. Those MS4s subject to NPDES permits must implement “control measures” in six areas, including a plan for eliminating illicit discharges (U.S. EPA 2000b).

PWSs should work with all MS4 utilities in the area of influence to gather existing information about storm water contamination. MS4 utilities may need to install or retrofit structural BMPs, such as retention ponds, to reduce contamination.

2.4.2.4 What BMPs Can Help Alleviate Nonpoint Sources?

The following sections briefly describe BMPs for agricultural, forestry, and urban sources of *Cryptosporidium*; detailed descriptions are provided in Appendix E. Your watershed control program plan must discuss how these or any other BMPs you choose will be implemented in the area of influence. EPA Section 319 grants and Clean Water State Revolving Fund loans can be used for nonpoint sources and watershed management purposes.

Agricultural BMPs

- *Management Programs*

The U.S. Department of Agriculture recommends the following “control points” for controlling pathogens (USDA 2000):

- Preventing initial infection by controlling pathogen import to the farm
- Controlling the reproduction and spread of the pathogen throughout the farm
- Managing waste
- Controlling pathogen export from the farm

PWSs should work with local soil conservation districts or cooperative extensions for technical assistance with BMPs.

BMPs that can reduce pathogen loading include the following:

- Composting
- Waste management (manure storage and land application)
- Grazing management
- Feedlot runoff diversion
- Buffer or filter strips

- *Composting*

- Can effectively reduce pathogen concentrations
- Entire waste mass should be uniformly treated and there should be no cold spots

- *Buffer Strips*

- Provide buffer between area of manure application or grazing and adjacent streams or lakes
- USDA (2000) recommends that buffer and filter strips be considered secondary practices for pathogen control and be used in conjunction with control measures

- *Grazing Management*

- Managed grazing can be cheaper and less environmentally damaging than confined feeding and unmanaged grazing. It decreases feed, herbicide, equipment, and fertilizer costs, while reducing erosion and increasing runoff infiltration and manure decomposition rates (Ohio State University Extension, undated).

- In managed, or rotational, grazing, a sustainable number of cattle or other livestock graze for a limited time (usually 2-3 days) on each pasture before being rotated to the next pasture.
- *Manure Storage*
 - Manure storage facilities allow farmers to wait until field conditions are more suitable for land application.
 - Manure storage facilities should be designed to prevent discharge through leaching or runoff. They should be lined, and if possible, covered. Facilities that are not covered should be designed to contain precipitation and runoff from a 25-year 24-hour storm.
- *Land Application of Manure*
 - Several precautions taken in manure application can prevent runoff from entering surface water, reducing the likelihood of *Cryptosporidium* contamination.
 - Manure should not be applied to frozen ground or before predicted rainfall, or near tile drains or dry wells or to land subject to flooding.
 - For pastures to be used for grazing, waste should be stored for at least 60 days and then applied at least 30 days before the scheduled grazing period, to avoid infection of the animals.
- *Feedlot Runoff Diversion*
 - Diverting clean water before it drains into the feedlot can significantly reduce the amount of wastewater that needs to be managed.
 - All roofs that could contribute to feedlot runoff should have -
 - gutters
 - downspouts
 - outlets that discharge away from the feedlot

Forestry BMPs

- Logging can cause increased erosion, leading to increased runoff and making it more likely that *Cryptosporidium* present in wildlife will reach the source water. Logging can also cause elevated sediment levels, resulting in high turbidity, which affects water treatment efficiency. Examples of forestry BMPs are listed below -
 - filter strips
 - streamside or riparian management zones
 - logging roads should be constructed to minimize runoff
 - road runoff should be diverted away from streams and prevented from channelizing

- loggers should minimize soil disturbance and compaction on skid trails

Urban/Suburban BMPs

See <http://www.epa.gov/owm/mtb/mtbfact.htm> for fact sheets on technologies and BMPs municipalities can use to reduce contamination from wastewater and stormwater.

- *Buffer Zones*
 - For watersheds in urban areas, buffer zones help to protect development on the floodplain from being damaged when the water is high, as well as protect the stream from the effects of the development.
 - The extent to which buffer zones reduce *Cryptosporidium* loading is not well understood; therefore, they should be used to augment, rather than replace, other watershed management practices.
- *Dry Detention Basins*
 - Dry detention basins temporarily store stormwater runoff and release the water slowly to allow for settling of particulates and the reduction of peak flows.
- *Infiltration Devices*
 - Infiltration devices remove pathogens and particles by adsorption onto soil particles and filtration as the water moves through the soil to the ground water. Infiltration devices include (NALMS 2000) -
 - infiltration basins
 - infiltration trenches
 - dry wells
- *Sand Filters*
 - Sand filters can be used to treat storm water runoff from large buildings and parking lots.
- *Wet Retention Ponds*
 - Ponds can effectively reduce suspended particles and, presumably, some pathogens, by settling and biological decomposition.
 - There is concern, however, that ponds attract wildlife that may contribute additional fecal pollution to the water, rather than reducing contamination.

- *Constructed Wetlands*
 - Constructed subsurface flow wetlands (where wetland plants are not submerged) can reduce *Cryptosporidium* and bacteria concentrations in wastewater (Thurston et al. 2001).
 - Wetlands may also be useful for treating storm water or other polluted water.
- *Runoff Diversion*
 - Structures can be installed in urban settings to divert clean water flow before it reaches a contamination source. Structures that channel runoff away from contamination sources include stormwater conveyances, such as -
 - swales
 - gutters
 - channels
 - drains
 - sewers
- *Pet Waste Management*
 - Municipalities can implement pet waste management programs to encourage pet owners to properly collect and dispose of their animals' waste.
- *Water Conservation*
 - Can help preserve the amount of water available for use, especially during times of drought.
 - Can also decrease the amount of wastewater and stormwater generated, thereby protecting the quality of the water supply (U.S. EPA 2002d)
 - The following are examples of water conservation methods -
 - low-flow toilets and showerheads
 - reducing lawn watering
- *Low Impact Development*
 - Low impact development tries to reduce the amount of impervious cover, increase natural lands set aside for conservation, and use pervious areas for more effective stormwater treatment of residential and commercial developments.
- *Septic Systems*

- Failing septic systems can result in clogging and overflow of waste onto land or into surface water.
 - Water systems should work closely with the local regulatory authority to ensure that septic system codes are being properly enforced and to strengthen codes where necessary.
 - Utilities should encourage residents with septic systems in the watershed to understand their systems and the proper maintenance that their systems require. Cooperative extensions can work with residents on this issue.
-
- **Wildlife BMPs**
 - Steps taken to prevent wildlife from contaminating source water vary with the source and type of wildlife. The following are examples of wildlife BMPs -
 - boats with noisemakers to scare seagulls and geese away
 - fences on the water's edge to keep out larger land animals and humans

2.4.3 Writing the Watershed Control Plan

Your plan must establish goals and define and prioritize specific actions to reduce source water *Cryptosporidium* levels. The plan must explain how the actions are expected to contribute to the goals, identify watershed partners and their roles, identify resource requirements and commitments, and include a schedule for plan implementation (40 CFR 141.725(a)(3)(iii)).

The Center for Watershed Protection provides basic templates to help with design of watershed protection programs, including steps systems can take in seven areas: watershed planning, land conservation, buffer zones, stormwater BMPs, non-stormwater discharges, watershed stewardship programs, and unique tools (e.g., spill response). Templates are available at www.stormwatercenter.net.

2.4.4 How States Should Assess Plans

Vulnerability Analysis

The vulnerability analysis should evaluate the potential for the water supply to draw water contaminated with *Cryptosporidium*. *Cryptosporidium* prevalence and the natural sensitivity of the water source should be considered together to determine the potential susceptibility of the drinking water source to contamination. The utility should define an area of influence for its water supply and provide an explanation of the assumptions that guided the delineation of that area of influence. The vulnerability analysis should take into account hydrologic and hydrogeologic factors, intake location, fate and transport characteristics of *Cryptosporidium* oocysts, and characteristics of potential sources

of *Cryptosporidium* in the area of influence. In addition, the vulnerability analysis should address the prevalence of different *Cryptosporidium* sources within the area of influence. Some assessment criteria that States can use during their review of vulnerability analyses are provided in Table 2.1. Additional criteria may be appropriate, based on site-specific characteristics of the area of influence and sources of *Cryptosporidium* contamination.

Identification and Analysis of Control Measures

The water supply must identify what measures could be taken to reduce or eliminate sources of *Cryptosporidium* identified in the vulnerability analysis (40 CFR 141.725(a)(3)(ii)). These control measures should be discussed in enough detail that the water supply has demonstrated it has a realistic understanding of what would be needed to implement the measures. The water supply should include an accurate estimate of control measure costs, as well as discussion of the political feasibility of implementation. Thoughtful estimates should be included of how much time the implementation of specific control measures would take, including any special considerations, such as seasonal restrictions.

In addition, the system must address how implementation of the control measures will impact *Cryptosporidium* loading in the watershed (40 CFR 141.725(a)(3)(ii)). The utility should discuss the degree to which control measures would control specific sources of *Cryptosporidium*. It should also provide context of the overall impact of the implementation of the control measures, addressing which control measures will be applied to *Cryptosporidium* sources that are significant in size or close to the water supply intake, and how effective the utility thinks they will be. Some assessment criteria that States can use during their review of the utility's discussion of control measures are provided in Table 2.1.

The Watershed Protection Plan

The watershed protection plan must address goals and define and prioritize specific actions to reduce source water *Cryptosporidium* levels. The plan must explain how actions are expected to contribute to the specified goals, identify partners and their roles, describe resource requirements and commitments, and include a schedule for plan implementation (40 CFR 141.725(a)(3)(iii)). Some assessment criteria for States to use during the review of watershed protection plans are provided in Table 2.1.

Cryptosporidium control measures included in watershed protection plans may include such diverse activities as structural BMPs, land use control regulations, and public education. Each of the activities should have a timetable for implementation, a budget, and details about how the activity will be implemented.

Utilities will have the maximum opportunity to realize their watershed protection goals if they have complete ownership of the watershed. Utilities should include in their watershed protection plan a description of efforts that will be made to obtain ownership, such as any special programs or budget. When complete ownership of the watershed or area of influence is not practical, the system should explain what efforts will be made to gain ownership of critical elements, such as reservoir or stream shoreline and access areas.

Where ownership of land is not possible, utilities should describe plans to obtain written agreements that recognize the watershed as part of a public water supply. As much as possible, maximum flexibility should be given to the utility to control land uses which could have an adverse effect on the water quality. Utilities should include with these descriptions an explanation of how they will ensure that landowners will comply with the agreements.

Watershed control plans must identify watershed partners and their roles (40 CFR 141.725(a)(3)(iii)). Plans should document the efforts to be made to establish voluntary local partnerships, including solicitation of private individuals living within the defined area of influence who are likely to be affected by decisions made as part of the watershed protection program, whose participation is important for the success of the program. Plans should also document how members of municipal or other local governments or political subdivisions of the State that have jurisdiction over the area of influence will participate in the watershed protection effort. Watershed protection plans should include descriptions of how the proposed local partnership has or will identify and account for any voluntary or other activities already underway in the area of influence that may reduce or eliminate the likelihood that *Cryptosporidium* will occur in drinking water.

Table 2.1 Assessment Criteria for Use By States When Reviewing Watershed Control Program Plans

Assessment Criteria	Addressed in Sufficient Detail?
Vulnerability Analysis	
Has the area of influence been delineated in appropriate detail, taking into consideration available information about <i>Cryptosporidium</i> fate, transport and local hydrogeological characteristics? Have sensitive areas been identified?	
Is the scale of the delineation appropriate for the watershed plan? Does it provide a level of detail sufficient for effective decisions to be made?	
Has the intake location been identified relative to the water body?	
Is any information available about time of travel in the watershed?	

Assessment Criteria	Addressed in Sufficient Detail?
Does it seem that all activities within the watershed that could result in <i>Cryptosporidium</i> contamination of the water supply have been identified and located?	
Have contaminant sources been located and described relative to the drinking water source intake location?	
Have the likelihood and timing of releases of contamination been addressed?	
Are there permitted wastewater discharges (NPDES) of concern? If there are wastewater treatment plants in the area of influence, systems should include information about their size, discharge quantity, and whether there has been any recent significant noncompliance with permit conditions.	
Are sludge disposal areas identified and characterized? Are there any locations in the watershed where biosolids have been applied? Have they been identified? When in the year are they applied?	
Have stormwater discharges been located? Are there any discharges directly into the surface water supply?	
Have septic systems been identified and located? What information is available about their age, condition, design, and siting?	
Has land use zoning been characterized?	
If land uses in the watershed include agriculture, have the types of farming been identified? Are feedlots located? Are fields where manure is spread identified?	
Have Concentrated Animal Feeding Operations (CAFOs) been identified and located?	
Have natural sources of <i>Cryptosporidium</i> been identified and located?	
Have recreational areas (e.g., campgrounds, trailer parks) been identified and located?	
Has any on-site landfilling, land treating, or surface impounding of waste other than landscape waste or construction and demolition debris taken place, and will such circumstances continue?	
Does the vulnerability analysis address the effectiveness of physical barriers (e.g., geology, hydraulic conditions, intake structure and location) at preventing the movement of contaminants to the drinking water source?	
Have tributaries or areas of the reservoir with high bacterial readings been identified? If so, where are they located relative to the drinking water intake?	
If <i>Cryptosporidium</i> monitoring data exist for the watershed, have results been addressed and discussed?	
Have recreational uses of the surface water supply been identified? Has the effect of those uses on <i>Cryptosporidium</i> loading been addressed?	

Assessment Criteria	Addressed in Sufficient Detail?
Are there portions of the watershed with high percentages of impervious surfaces which might lead to increased stormwater runoff?	
Is water quality monitoring and assessment information (305(b) Report) available?	
Have existing best management practices or controls been identified and located?	
Is there any information available about the effectiveness of current pollution prevention activities?	
Potential Control Measures to Control <i>Cryptosporidium</i> Contamination	
Do the control measures proposed specifically address the reduction of <i>Cryptosporidium</i> contamination?	
Would the implementation of the proposed control measures take place in areas where there would be an impact on <i>Cryptosporidium</i> loading into the water supply?	
Do the proposed control measures seem economically and politically feasible?	
If the proposed control measures are ongoing, has the utility explained how they would be sustained?	
Is the water utility in a position where it could implement the control measures itself, or would other parties be responsible?	
If other parties would be responsible for implementation, are those parties motivated and reliable? What agreements between the utility and those parties exist that document implementation responsibilities?	
How does the utility track control measures implemented by other parties?	
Has the water system responded adequately to concerns expressed about the source or watershed area in past inspections and sanitary surveys?	
Watershed Control Program Plan	
Does the plan specifically address potential and existing <i>Cryptosporidium</i> sources in the watershed?	
Have the proposed actions in the plan been clearly defined and sufficiently addressed?	
Does the plan explain how the actions described are expected to contribute to specified goals?	
Does the plan prioritize its proposed efforts? Does it define short-term and long-term actions and prioritize them?	
Does the plan include cost estimates for implementation of proposed actions?	
Does the plan include, in detail, what other resources will be required to implement the watershed control measures? Does it identify the source(s) of those resources?	

Assessment Criteria	Addressed in Sufficient Detail?
Does the plan include an implementation schedule?	
Does the plan assign responsibilities for implementing short-term and long-term actions?	
How reliable are the organizations that will be carrying out the source protection activities?	
Has an individual been identified as the responsible party for the plan?	
Will the entire watershed for the source be protected? Will the utility try to purchase all land within the watershed? If not, will critical elements of the watershed be protected or purchased by the utility?	
If the water system cannot purchase portions of the watershed, does it propose to have written agreements with the landowners concerning land use?	
Where access is limited, will the watershed be inspected regularly for new potential and actual sources of contamination?	
Does the plan address all existing regulations for the watershed or area of influence?	
Does or will the water system employ adequately qualified personnel to identify watershed and water quality problems? Who is given responsibility to correct these problems?	
Have the stakeholders in the watershed or area of influence been identified?	
Were stakeholders involved with the plan's development?	
Is it proposed that the water system will actively interact with other agencies that have control or jurisdiction in the watershed? Are their policies or activities consistent with the water system's goal of reducing source water <i>Cryptosporidium</i> levels?	
How does the watershed protection plan propose to coordinate protection efforts? Will there be a committee of stakeholders?	
How will the utility track progress of the implementation of the watershed controls? Does the plan describe how the utility intends to measure the success of projects?	

2.5 Maintaining Approval of a Watershed Control Program

2.5.1 Annual Watershed Control Program Status Report

The annual watershed control program status report must describe the water system's implementation of the approved plan and assess the adequacy of the plan for meeting the system's stated goals. The annual report must explain how the system is addressing any shortcomings in plan implementation, including those previously identified by the State or by the system during a watershed survey. If the system needs to make substantial changes to its approved program, it must explain the

nature of those changes and why they are being made. If the changes are likely to reduce the level of source water protection, the water utility must explain what actions it will take to mitigate the effects (40 CFR 141.725(a)(4)(i)). If there have been any changes to components of the program, such as partnerships or stakeholder groups that have been created or have dissolved, the annual report should include this information, along with a description of how the change will affect the watershed control program plan.

The annual status report must describe progress being made implementing individual control measures (40 CFR 141.725(a)(4)(i)). Progress should be compared with the original timetable provided in the watershed control program plan. Implementation delays should be explained, and actions to prevent further delays should be proposed.

The original watershed control program plan should include specific measures by which the utility can evaluate the effectiveness of the program. Annual status reports should provide updates on those measures of program effectiveness as the watershed practices are implemented. The report should address progress being made on high priority activities and, to the extent possible, evaluate whether projects are achieving their objectives. The report should also identify emerging issues and incorporate them into the watershed protection program. Since annual status reports must be available to the public on request, reports must be written in plain language format (40 CFR 141.725(a)(4)(iv)).

2.5.2 State-Approved Watershed Sanitary Survey

The annual watershed sanitary survey must be conducted according to State guidelines and by persons approved by the State to conduct watershed surveys. The survey must encompass the area of influence. At a minimum, the watershed survey must assess the priority activities identified in the plan and identify any significant new sources of *Cryptosporidium* (40 CFR 141.725(a)(4)(ii)). States developing a watershed sanitary survey program may wish to use the watershed sanitary survey manual developed by the California Department of Health Services, and the California/Nevada Section of AWWA (the manual is available from the California/Nevada Section).

The watershed survey should be conducted by competent individuals such as engineers, sanitarians, or technicians with experience in the operation of water systems and a sound understanding of public health principles and waterborne diseases. Other means of assessing inspector qualifications include whether the inspector has attended formal training sessions, whether he or she has documented on-the-job training, whether the training received is appropriate for the type and size of system being surveyed, and whether the inspector is knowledgeable about State and federal drinking water regulations.

The annual watershed survey should address the following areas:

- Review the effectiveness of the watershed control program to date
- Identify any new significant actual or potential sources of *Cryptosporidium*
- Verify and re-evaluate the vulnerability analysis
- Verify that the utility has control over watershed areas and activities specified as its responsibility in the Watershed Protection Plan
- Confirm that public access is properly restricted from areas identified in the Watershed Protection Plan
- Confirm that fencing and postings have not been vandalized or removed
- Identify any significant hydrological changes in the watershed that could affect *Cryptosporidium* loading
- Inspect the intake structure and identify any modifications to its location or design

A final survey report must be submitted to the State for approval (40 CFR 141.725(a)(4)(ii)). The report should be completed as soon as possible after the survey is conducted. The length of the report will depend on the findings of the survey and the size and complexity of the watershed. The survey report should include: 1) the date of the survey; 2) who was present during the survey; 3) survey findings; 4) recommended improvements to the identified problems; and 5) the dates for completion of any improvements.

The annual watershed survey reports must be written in a plain language format. Survey results must be made available to the public upon request. The State may withhold portions of the survey report based on security considerations (40 CFR 141.725(a)(4)(iv)).

2.5.3 Request for Re-Approval

If the water system intends to continue to receive 0.5 log *Cryptosporidium* removal credit beyond the approval period, it must submit a written request for review and re-approval of the watershed control program. The request must be provided to the State at least six months before the current approval period expires or by a date previously determined by the State. The request must include a summary of activities and issues identified during the previous approval period and a revised plan that addresses activities for the next approval period, including any new actual or potential sources of *Cryptosporidium* contamination and details of any proposed or expected changes to the existing State-approved program. The revised plan must address goals, prioritize specific actions to reduce source water *Cryptosporidium*, explain how actions are expected to contribute to achieving goals, identify partners and their roles, describe resource requirements and commitments, and include a schedule for further plan implementation (40 CFR 141.725(a)(4)(iii)).

2.5.3.1 Describe Implementation of Plan

The request for re-approval should build upon progress that has been made during the previous watershed protection period. It must update program goals and priorities for *Cryptosporidium* control measures and explain how proposed actions will contribute to specified goals. The request for re-approval must include involved parties and their roles, resource requirements and commitments, and schedules for implementation. New actual or potential sources of *Cryptosporidium* contamination identified in previous annual watershed surveys must be addressed, (40 CFR 141.725(a)(4)(iii)). Each new watershed control measure introduced should have a timetable for implementation, a budget, and details about how the activity will be implemented. The request for re-approval should also include updated measures by which the utility can evaluate the effectiveness of the program.

2.5.3.2 Describe How System Is Addressing Any Problems

As part of the request for re-approval, the water system should identify any unresolved problems it encountered during the previous watershed protection period that interfered with achieving the stated watershed protection goals. The system should address how it intends to resolve the problems or change the watershed protection plan to work around the problems. If the changes proposed are likely to reduce the level of source water protection, the utility should explain what actions it will take to mitigate the effects.

2.5.3.3 Describe Need for Changes in Plan

Many watershed protection plans will require periodic revisions to ensure that their actions and priorities remain up-to-date. As part of the request for program re-approval, the utility should describe what changes need to be made to the watershed protection plan and explain why those changes should be made. Any new control measure introduced should be accompanied by a budget, timetable for implementation, and details about how the measure will be implemented. The utility should include an explanation of how and why the watershed protection plan's priorities may change for the next approval period. The utility should also define measures by which it will evaluate the effectiveness of the revised program.

2.5.4 Guidance to States on Re-Approval

The State should consider several sources of information when reviewing requests for re-approval. It should refer to a system's annual watershed control program status reports to evaluate whether progress made so far is acceptable and that previous timetables have been accurate. The State should review whether the identified responsible parties are participating reliably and in a timely manner.

The State should review the annual watershed surveys to ensure that newly discovered actual or potential sources of *Cryptosporidium* contamination have been addressed in the request for re-

approval and feasible control measures have been proposed. The State should also refer to the most recent sanitary survey conducted of the water system to see that source protection concerns regarding pathogen contamination are being addressed. States can use the watershed control program plan assessment criteria provided in Table 2.1 to guide their review of the proposed changes to the plan.

As part of the re-approval process, States should consider whether a utility's measures of program effectiveness for the previous approval period were useful and accurate. If not, States should ensure that the request for re-approval includes improved ways to measure program effectiveness.

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3.0 Alternative Source/Intake

3.1 Introduction

Changing the water source or intake location can improve source water quality and reduced treatment requirements for the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). The rule states that systems may be classified in a bin based on monitoring of an alternative source or intake location or monitor using an alternative procedure for managing the timing of withdrawal; this monitoring must be conducted concurrently with their existing intake or withdrawal practice. After monitoring, a system would then choose which source, intake location, or intake procedure it will use based on bin classification results. (40 CFR 141.725(b)(1))

Applicability

The LT2ESWTR specifies the sample locations for systems with **presedimentation basins** and **raw water off-stream storage** (40 CFR 141.704). These locations are after the basins; therefore, this option should **not** be considered by systems with those treatment processes.

Since the LT2ESWTR requires that alternative monitoring must be conducted concurrently with source water monitoring (40 CFR 141.725(b)(1)), this toolbox option needs to be evaluated **prior to the start of source water monitoring**.

This chapter discusses the concurrent monitoring options of changing sources, moving the plant intake, and managing the timing or level of withdrawal and is organized as follows:

- 3.2 Changing Sources - discusses factors to be considered in changing sources, including advantages and disadvantages and influence of source water characteristics on existing treatment requirements.
- 3.3 Changing Intake Locations - discusses the applicability of changing the intake locations and variables affecting *Cryptosporidium* concentrations in reservoirs, lakes, streams, and rivers.
- 3.4 Changing Timing of Withdrawals - describes different approaches, and advantages and disadvantages to changing the timing of withdrawals.

3.2 Changing Sources

In order to be able to relocate an intake to a different source, a system would need to identify an unallocated source within a reasonable distance of its treatment plant. The new source would require sufficient unallocated flow to meet the system's needs, including those for peak flow and future growth. The effect of the different water quality on the existing treatment process should also be considered.

3.2.1 Advantages and Disadvantages

The main advantage of changing sources as an approach to dealing with higher *Cryptosporidium* levels in a current source is avoiding the addition of a new treatment process. The capital expense of a new well or new intake may be less than the expenses associated with installing and operating a new treatment technology. In addition to having a lower *Cryptosporidium* concentration, the new source may also have better water quality that could reduce treatment costs. Systems should assess any potential new source to ensure its integrity, quantity, and quality. In addition, switching to a new source often requires approval by the State.

A disadvantage associated with changing sources is that the different source water may respond differently to the treatment train already existing at the plant. This may require changes in plant operating procedures, such as changing the type and amount of coagulant added, the length of filtration runs, and the dose of disinfectant added. Another disadvantage is that the source may be lower in *Cryptosporidium* concentration but have higher concentrations of other contaminants. There may also be legal and environmental issues associated with tapping a new source. Plant standard operating procedures (SOPs) should be updated if a new source is added. Finally, the cost of installing a new intake and transmission line should be considered; depending on the location of the source or intake in relation to the plant or to existing transmission lines, a new source/intake could be more expensive than other toolbox options.

3.2.2 Evaluation of Source Water Characteristics for Existing Treatment Requirements

If a new source is to be introduced to an existing treatment plant, the treatability of the new water by the existing process should be considered. For example, in a conventional treatment train consisting of coagulation, sedimentation, and dual media filtration, each source water will have unique coagulation properties depending on its characteristics. Organic content, alkalinity, and pH all affect the coagulation process. Consequently, water quality parameters including pH, alkalinity, total organic carbon (TOC), UV₂₅₄, turbidity, and iron and manganese concentrations should be measured and evaluated against the existing water and the treatment train. If coagulation is used as a part of the

treatment process, jar tests should be conducted to determine the coagulation and settling properties of the new water and to aid in calculating the required dose of coagulant. (See American Water Works Association (AWWA) Manual M37, *Operational Control of Coagulation and Filtration Processes* for more information on jar testing.) Pilot plant studies can also help determine the treatability of a proposed new source.

3.3 Changing Intake Locations

Another method for reducing *Cryptosporidium* source concentrations is to move the intake within the same source. This could involve relocating an intake within a source or changing the depth from which the intake draws.

3.3.1 Applicability

Relocating an intake can be a good strategy if an obvious source of *Cryptosporidium* is present which can easily be avoided by moving the location of the intake. One example of such a situation is if an intake could be moved upstream of a municipal wastewater discharge in a river, where it had previously been located downstream of the discharge.

3.3.1.1 Advantages and Disadvantages

One advantage of moving the location of an intake is its potentially low relative cost, if the distance the intake must be moved is relatively short. This option could be particularly attractive if an existing intake structure can be used to withdraw water from a different depth, resulting in decreased *Cryptosporidium* concentrations.

Disadvantages could include significant amounts of excavation and piping, as well as additional pumping if the intake must be relocated a considerable distance. Also, altering the intake may not bring the desired reduction or provide any additional protection against future increases or spikes in *Cryptosporidium* concentration.

3.3.2 Reservoirs and Lakes

Several variables can affect the concentration of *Cryptosporidium* at a particular location in a reservoir or lake, including the intake depth, the way in which the lake mixes, the thermal properties of the lake, and the proximity of the intake to streams and other discharges. It is recommended that a water system develop an SOP for water withdrawal based on the specific conditions of the waterbody being used as the source.

3.3.2.1 Depth

The intake depth can significantly change the quality of the water being drawn and used. In general, shallow intakes are more likely to draw water exposed to recreational activity and surface water runoff. Deeper intake locations are often more protected from sources of *Cryptosporidium*, unless an intake location is so deep that it draws water containing re-suspended material from the lake or reservoir bottom. Water systems are often well-advised to draw water from intermediate depths, where they can avoid higher oocyst concentrations that may exist near the lake or reservoir surface, and also avoid particles that may be stirred up near the bottom.

3.3.2.2 Stratification and Mixing

Another factor that can affect the depth profile of *Cryptosporidium* in a lake or reservoir is the amount of stratification or mixing present. Larger lakes and reservoirs often stratify, especially in the summer months, forming a hypolimnion (a cold lower layer) and an epilimnion (a warm upper layer) separated by a thermocline. There is very little mixing between these layers when a lake is strongly stratified. Particles may settle through the layers, but there is little other mixing. The epilimnion is often well mixed because of the mixing action of wind. Therefore, it is likely that *Cryptosporidium* may be present at uniform concentrations throughout the epilimnion. *Cryptosporidium* oocysts that have attached to particles and settled will have a concentration gradient in the hypolimnion. The shape of any concentration gradient will depend on local conditions such as temperature, stream inflows, and particle settling rates. Lakes or reservoirs that are strongly stratified and have a high input of organics can often develop anoxia in the hypolimnion. Therefore, all water quality parameters should be considered before determining the depth from which to draw the water. Extremely high withdrawal rates may provide enough energy to overcome stratification and draw from the layer outside of where the intake is located.

3.3.2.3 Proximity to Inflows

The proximity of the intake to stream inflows may affect the quality of the intake. Streams carrying agricultural or urban runoff can cause water quality degradation if located too close to a source water intake. States et al. (1998) reported an increase in *Cryptosporidium* concentrations with wet weather events, particularly as the sampling location became closer to the contamination source. Kortmann (2000) reported a system substantially reduced coliform bacteria in their source water by moving their intake further away from a stream which drained an agricultural area and by installing an artificial partition in the reservoir to limit the exchange of water between the stream input and the rest of the lake.

3.3.3 Streams and Rivers

There are several factors to consider when deciding where to locate an intake on a river including depth, flow hydraulics, seasonal effects, and upstream sources of contamination.

3.3.3.1 Depth

Depth is not as likely to affect *Cryptosporidium* concentrations in small rivers and streams as it is in lakes and reservoirs. Fast moving or shallow streams are likely to be fairly mixed across all depths. In contrast, deeper and slower moving rivers may be less mixed and may show some concentration gradient of *Cryptosporidium* with unattached oocysts being greater near the surface and oocysts attached to particles being greater near the bottom. In rivers and streams, intakes located near the bottom are more likely to draw sediment and other particles resuspended from the bottom.

3.3.3.2 Flow and River Hydraulics

Hydraulics of the river and the flow around the intake are extremely important in determining the quality of water that enters the system. In general, portions of a stream or river with lower velocities and less turbulence will contain less sediment and possibly less *Cryptosporidium* oocysts. Care should also be taken to make sure that the design of the intake does not cause turbulence which might stir up sediments.

3.3.3.3 Upstream Sources of Contamination

Any potential sources of contamination upstream of a new intake should be identified and their impact considered with respect to both biological and chemical contamination. Contaminant sources of particular concern for *Cryptosporidium* include animal feeding operations and sewage outfalls. If an intake cannot be located upstream of such a source, then locating it as far as possible downstream to allow time for particles to settle may be the next best alternative. Analyses of the vulnerability of a stream source should be made on a regular basis. Any changes in the vulnerability of a source to *Cryptosporidium* or other contaminants should be reported to the primacy agency.

3.3.3.4 Seasonal Effects

Cryptosporidium concentrations tend to be higher during runoff events, particularly in the spring. Although it is probably not feasible to cease withdrawals during such incidents, it may be possible to alter flow rates and coagulant doses to offset the effect of such events.

3.4 Changing Timing of Withdrawals

The LT2ESWTR allows the option of changing the timing of withdrawals to obtain a lower source water concentration of *Cryptosporidium* for bin assignment (40 CFR 141.725(b)(1)). For implementation of this option, the system must then continue to draw source water in the same manner as conducted for *Cryptosporidium* source water monitoring (40 CFR 141.725(b)(3)). The operating conditions under which the samples were collected for the LT2ESWTR must be reported and submitted to the State with the monitoring results (40 CFR 141.725(b)(2)).

3.4.1 Toolbox Selection Considerations

As stated above, the change in timing must be consistent during *Cryptosporidium* monitoring and during routine operation after monitoring. Additionally, the LT2ESWTR does not allow source water monitoring to deviate from a predetermined schedule by more than 2 days, unless extreme conditions or situations arise that prevent sampling (40 CFR 141.703(b) and (c)). Given these limitations, the following provides examples of recommended and not recommended approaches.

Recommended Approaches

- Changing the timing of withdrawal on a daily basis (e.g., from the afternoon to morning to avoid suspended material stirred up by recreational water use).
- Use a water quality indicator to avoid short-term increases in *Cryptosporidium* due to short-term weather or source water contamination events. For example, if a system routinely experiences a spike in turbidity and subsequently, *Cryptosporidium*, for a 12-24 hour period following a storm event, then the system may choose to set up a monitoring plan that delays withdrawal for a 24 hour period when detecting a spike in turbidity.

Approaches Not Recommended

- Limiting withdrawal in response to seasonal effects or weather effects lasting on the order of days. This would be a difficult monitoring strategy to follow and stay in compliance with the 2 day sampling window.

3.4.1.1 Advantages and Disadvantages

The advantage of changing the timing of withdrawals is it requires no treatment changes, only a change in operations. For systems with multiple sources it also allows the greatest flexibility in meeting water quality goals.

A disadvantage of relying on changing withdrawals to lower *Cryptosporidium* concentrations is that it may result in decreased flexibility, since systems must follow the same withdrawal practices they did during *Cryptosporidium* source water monitoring. If electing to practice a withdrawal approach that defers withdrawal during likely *Cryptosporidium* events, then a system may need some raw water storage capacity.

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4.0 Bank Filtration

4.1 Introduction

Bank filtration is a surface water pretreatment process that uses the bed and bank of a river (or lake) and the adjacent aquifer as a natural filter. In optimal locations and under optimal conditions, bank filtration is suitable for accomplishing sufficient *Cryptosporidium* removal to partially meet the requirements of the Long Term 2 Enhanced Surface Water Treatment Rule. To accomplish this, a pumping well located in the adjacent aquifer induces surface water infiltration through the bed and bank. Bank filtration differs significantly from artificial recharge and from aquifer storage and recovery, both of which rely on engineering works to move water into specially constructed and maintained recharge basins or wells for infiltration into or replenishment of the aquifer. Although microorganism removal can occur in such engineered systems, they are not bank filtration. This is because bank filtration relies solely on the natural properties of the surface water bed and aquifer, unmodified by engineered works or activity, except for the recovery of ground water via a pumping well.

A significant proportion of microorganisms and other contaminants are removed by contact with the aquifer material as the water travels to the well through the subsurface. Flow to the well may be horizontal or vertical, but more typically will take a variable path with both horizontal and vertical components. The water which has been induced to infiltrate through the river's bed and bank is known as "bank filtrate." It will be mixed with ambient ground water that has taken a different and typically longer path to the well. The ambient ground water may have originated as bed or bank infiltration from an upstream portion of the river or from a lake. It may have originated from infiltrating precipitation. Regardless, ambient ground water is likely to contain different contaminants and contaminant concentrations than bank filtrate because its origin and flow pathways differ significantly. Ambient ground water should not be assumed to be uncontaminated.

Aquifers suitable for bank filtration are composed of unconsolidated, granular material (i.e., grains) and have open, interconnected pores that allow ground water to flow. Pathogen removal is enhanced when fine-grained sediment is present along the flow path. Geologic units consisting primarily of fine-grained (e.g., clay-sized) materials will have higher removal but will be incapable of yielding economically significant water flow rates. In aquifers containing both sand-sized and finer grains, the presence of fine grains increases the possibility that pathogens will encounter a grain surface. This is because flow is slower and flow paths are longer than they would be in aquifers without such fine grains. Microorganisms will be removed from flow as they contact and attach to grain surfaces. Although microorganism (e.g., *Cryptosporidium*) detachment can occur, it usually does so at slow rates (Harter et al., 2000). When little or no detachment occurs or when detachment is slow, microorganisms can become non-viable while attached to grain surfaces. Thus, bank filtration provides physical removal, and in some cases, inactivation, to remove pathogens from water supplies.

The purposes of this chapter are: 1) to clarify the requirements of the LT2ESWTR related to receiving *Cryptosporidium* removal credit for the use of bank filtration systems 2) to present the current state-of-the-science, advantages and disadvantages of *Cryptosporidium* removal by bank filtration; 3) to explain how local geologic and hydrologic conditions affect the functioning and effectiveness of bank filtration systems; and 4) to provide suggestions for optimal operation of bank filtration systems.

This chapter is organized as follows:

- 4.2 LT2ESWTR Compliance Requirements - describes requirements for receiving *Cryptosporidium* removal credits related to the proposed installation of bank filtration wells.
- 4.3 Toolbox Selection Considerations - describes the advantages and disadvantages of using bank filtration as a pretreatment technology.
- 4.4 Site Selection and Aquifer Requirements - characterizes surface water and aquifer types that are suitable for bank filtration.
- 4.5 Design and Construction - describes the types of wells eligible for bank filtration credits and the locations at which such wells are best placed.
- 4.6 Operational Considerations - describes issues relevant to the optimal operation of bank filtration systems in order to protect public health.

4.2 LT2ESWTR Compliance Requirements

Systems that propose to install bank filtration wells to meet any additional treatment requirements imposed by the LT2ESWTR may be eligible for 0.5 or 1.0 log *Cryptosporidium* removal credit (40 CFR 141.726(c)). Systems meeting all regulatory requirements (e.g. systems with conventional or direct filtration that meet the well siting requirements) receive *Cryptosporidium* log removal credit prior to construction of the production wells. For those systems which already use bank filtration as a component of their treatment process and which also have existing conventional or direct filtration treatment, the LT2ESWTR requires source water monitoring of produced water from the bank filtration well. This will determine the initial bin classification for these systems. Because their source water monitoring accounts for any bank filtration treatment, these systems are not eligible for subsequent additional bank filtration credits (40 CFR 141.704).

Systems using ground water under the direct influence (GWUDI) of surface water or bank filtered water without additional filtration must take source water samples in the surface water to

determine bin classification (40 CFR 141.704). This applies to systems using an alternative filtration demonstration to meet the *Cryptosporidium* removal requirements of the IESWTR or LT1ESWTR (40 CFR 141.173(b) and 141.552(a)). As a result, the requirements and guidance provided in this chapter do not apply to existing primacy agency actions providing alternative filtration *Cryptosporidium* removal credit for IESWTR or LT1ESWTR compliance.

4.2.1 Credits

The LT2ESWTR specifies the following design requirements for systems to receive log removal credit for bank filtration (40 CFR 141, Subpart W, Appendix A):

- Wells must draw from **granular aquifers** that are comprised of clay, silt, sand, or pebbles or larger particles. Minor cement may be present.
- The aquifer material **must be unconsolidated**, with subsurface samples friable upon touch.
 - Granular aquifers formed by alluvial or glacial processes are eligible for bank filtration credit.
 - Granular aquifers, either unconsolidated or partially consolidated, and mapped as earlier than Quaternary alluvium, must be considered on a case-by-case basis by the state to determine if they are too cemented, and therefore too fractured, to provide sufficient natural filtration.
 - Wells located in consolidated clastic aquifers (e.g., conglomerates), fractured bedrock aquifers, and karst limestone aquifers **are not** eligible for bank filtration credit.
- Only **horizontal and vertical wells** are eligible for bank filtration log removal credit.
 - Other ground water collection devices such as infiltration galleries and spring boxes are ineligible.
- Systems using horizontal or vertical wells located at least **25 feet** from the surface water source are eligible for a **0.5 log removal credit** and those located at least **50 feet** from the surface water source are eligible for a **1.0 log removal credit**.
 - Systems with vertical wells must identify the distance to surface water using the floodway boundary or 100 year flood elevation boundary as delineated on Federal Emergency Management Agency (FEMA) Flood Insurance Rate maps. If the

floodway boundary or 100 year flood elevation boundary is not already delineated, systems must determine the floodway or 100 year flood elevation boundary using methods substantially similar to those used in preparing FEMA Flood Insurance Rate maps.

- Systems with horizontal wells must measure the distance from the normal flow stream bed to the closest horizontal well lateral.
- Systems must **characterize the aquifer** at the proposed production well site to determine aquifer properties.
 - At a minimum, the aquifer characterization must include the collection of relatively undisturbed continuous core samples from the surface to a depth at least equal to the projected bottom of the well screen for the proposed production well.
 - The recovered core length must be at least 90 percent of the total depth to the projected bottom of the well screen and each sampled interval must be a composite of no more than 2 feet in length.
 - Each composite sample must be examined to determine if at least 10 percent of the grains in that interval are less than 1.0 mm in diameter. Each composite sample with at least 10 percent of the grains less than 1.0 mm in diameter is considered an interval with sufficient fine-grained material to provide adequate removal.
 - An aquifer is eligible for removal credit if at least 90% of the composited intervals contain sufficient fine-grained material as defined previously.

4.2.2 Monitoring Requirements

The LT2ESWTR requires systems to monitor turbidity in bank filtration wells to provide assurance that the assigned log removal credit is appropriate. The LT2ESWTR specifically requires the following monitoring (40 CFR 141.726(c)(1)):

- Turbidity measurements must be performed on representative water samples from each wellhead every four hours that the bank filtration system is in operation or more frequently if required by the state.
- Continuous turbidity monitoring at each wellhead may be used if the system validates the continuous measurement for accuracy on a regular basis using a protocol approved by the state.

- If the monthly average of daily maximum turbidity values at any well exceeds 1 NTU, the system must report this finding to the state within 30 days. In addition, within 30 days of the exceedance the system must conduct an assessment to determine the cause of the high turbidity levels and submit that assessment to the state for a determination of whether any previously allowed credit is still appropriate.

4.3 Toolbox Selection Considerations

Bank filtration is best suited to systems that are located adjacent to rivers with reasonably good surface water quality and that plan to use bank filtration as one component of their treatment process. For systems that can meet the aquifer requirements (section 4.4) and the design criteria (section 4.5), bank filtration can be an efficient, cost-effective pretreatment option to improve water quality (Berger, 2002). Medema et al. (2000) and Wang et al (2000, 2002) documented high removal of *Cryptosporidium* indicator organisms at production well sites in The Netherlands and in Louisville, Kentucky. There was very little occurrence of *Cryptosporidium* in river water at the Kentucky site and no *Cryptosporidium* was found in the well water at either site. The amount of *Cryptosporidium* removal at either site is unknown.

The efficient removal of indicator organisms at the Netherlands site was likely due to the relatively impermeable, fine-grained layer of river sediment present, as well as the effect of pyrite oxidizing to ironhydroxides. Ironhydroxides may enhance the attachment of microorganisms to riverbed sediments (Medema *et al*, 2000). In Louisville, Kentucky, an alluvial aquifer was chosen for the bank filtration site. Wang *et al* (2000, 2002) found that removal of particles increased with filtration distance of the riverbank filtration process, although most of the removal occurred at the surface of the riverbed, within the first two feet of filtration. Wang *et al* (2002) attributed the removal in their bank filtration system to a combination of mechanical filtering and biological activity (e.g., biofiltering) at the surface of the riverbed.

As discussed in section 4.4, only certain sites are suitable for bank filtration. It is important to understand the type of bed and aquifer material present, the dynamics of groundwater flow, and the potential for scouring of riverbed materials at a potential bank filtration site. The degree to which the bed and banks of surface water bodies may effectively filter *Cryptosporidium* may vary not only from site to site, but also at a single site over time.

4.3.1 Advantages and Disadvantages

4.3.1.1 Removal of additional contaminants

The two research sites with published data (Medema et al., 2000; Wang et al., 2000; Wang et al., 2002; Berger, 2002) have reported that bank filtration is effective at removing *Cryptosporidium*.

Bank filtration has also been shown at some sites to be an effective technology for attenuating a variety of additional microorganisms as well as particulates, ammonia, nitrate, pesticides (e.g., atrazine), heavy metals, ethylenediamine tetra-acetic acid (EDTA), alkylated and chlorinated benzenes and other organic contaminants, and disinfection by-product precursors (DBPs) in the form of natural organic matter (NOM) (Schijven et al., 2003; Tufenkji et al., 2002; Ray et al, 2002; Kuehn and Mueller, 2000). Bank filtration achieves the removal of these diverse contaminants by facilitating or enhancing physical and chemical filtering, sorption, reduction/oxidation, precipitation, ion exchange, and biodegradation (Schijven et al., 2003; Ray et al., 2002; Tufenkji et al., 2002). Bank filtration further reduces contaminant concentrations and especially shock contaminant loads from spills and intentional acts by providing for the multidimensional dispersion and dilution of contaminants (Ray et al., 2002).

The degree to which any particular contaminant will be removed via bank filtration depends on site-specific conditions. For example, under aerobic conditions, ammonia is often completely transformed, whereas such removal may not occur under more reducing conditions. Oxygen is usually significantly depleted within 5-15 feet of the riverbed, due to microbial activity in this zone. As infiltrating water becomes increasingly depleted of organic matter due to degradation, microbial activity diminishes, and the aquifer may be re-aerated at a certain distance from the riverbed (Tufenkji et al., 2002). The anaerobic part of the aquifer was observed to remove up to 99% of polar organic contaminants at a site in central Germany (Juttner, 1995). Miettinen et al (1994) found that almost 90% of the high molecular weight fraction of NOM had been removed at a bank filtration site in Finland.

The reduction in some treatment costs made possible by bank filtration results from a reduced need for other treatment technologies. When bank filtration decreases the concentration of dissolved organic carbon reaching a treatment plant, costs are lowered because a decreased proportion of dissolved contaminants needs to be adsorbed onto activated carbon filters. Thus, each filter is capable of operating for a longer period of time, and fewer replacement filters are needed. Particle and microorganism removal during bank filtration allows for more efficient filtration, use of membranes, and disinfection during subsequent treatment steps. The removal of ammonia means that the additional treatment step of oxidizing ammonia with chlorine may be unnecessary. The removal of nitrate when water is induced to flow through anaerobic areas may eliminate the need for expensive ion exchange or reverse osmosis treatment processes (Kuehn and Mueller, 2000). Finally, because it is effective at biodegrading many contaminants, bank filtration reduces the need for adding large quantities of flocculants to drinking water, thereby reducing both costs and the unhealthful effects of water treatment residuals (Kuehn and Mueller, 2000).

Another advantage of bank filtration as a pretreatment technology is that it acts to equalize fluctuations in contaminant concentrations observed in surface waters. This is due to the effects of dilution and dispersion which serve to spread peaks in contaminant concentrations over space and time by the time they reach wells. Contaminant concentration peaks may be due to variations in river water levels, seasonal effects, and runoff, in addition to spills, terrorist acts and emissions by municipal and industrial institutions (Kuehn and Mueller, 2000). Bank filtration also smooths out fluctuations in water temperature. Bank filtration is continuously active, and the decreased amplitude of the contaminant

peak by the time it reaches a well (an inherent result of subsurface transport through porous material) allows for easier and less expensive treatment by utilities with limited capabilities. In addition, the time lag between contamination of surface water and arrival of contaminant at a well would give utilities more of an opportunity to respond to a threat or an accidental spill. Kuehn and Mueller (2000) estimate that in many modern bank filtration systems bank filtrate spends anywhere from 5 to 15 days in the subsurface before reaching supply wells. At one site in the Netherlands, bank filtrate was estimated to spend 45-65 days in the subsurface before reaching the supply well (Medema, et al., 2000). Residence time depends on site-specific hydrogeology as well as bank filtration system design.

The removal of NOM during bank filtration is useful because NOM occurrence can result in the production of harmful disinfection byproducts, as discussed above. In addition, moderate to high concentrations of NOM in drinking water can result in unpleasant taste and odor. Finally, NOM removal via bank filtration can also aid in the removal of a large variety of additional organic and inorganic contaminants. These contaminants are sometimes made more mobile in surface and ground waters due to a partitioning process whereby they are attached to NOM, which is relatively mobile, and thereby carried along a flow path. The removal of NOM and associated contaminants prior to above-ground treatment is likely to lessen the overall cost of water treatment at a given facility.

4.3.1.2 Clogging of pores

Clogging of the surface water - ground water interface has the potential to be a problem with any riverbank filtration system, and results from physical, chemical, and biological processes. Partial clogging during riverbank filtration system operation is likely to be unavoidable (Wang et al., 2001), however its effects are not always deleterious. The disadvantage of clogging is that it can reduce hydraulic conductivity of the local riverbed and the aquifer, thereby temporarily or permanently reducing well yields. On the other hand, a limited accumulation of fine-grained sediments and the accompanying development of a biologically active zone can enhance pathogen removal. Indeed, this enhanced removal is a basic principle behind riverbank filtration as a water treatment technology. An optimal amount of clogging is beneficial because it can reduce the size of large pores or reduce entrances to pores in a stream bed or aquifer. Pore size reduction and decreased hydraulic conductivity also result in longer travel times which can result in additional pathogen inactivation. Transport of fewer pathogens is also likely because there are more opportunities for pathogen contact with aquifer grain surfaces.

Physical clogging of the surface water - ground water interface results from the deposition of fine-grained, suspended sediment at the interface and in the near surface pores. The deposition and growth of microorganisms also contribute to physical clogging. This clogging may be exacerbated during periods of low surface water discharge, and is most apparent near the river's edge where flow velocities are generally lower than at the center of the river. Chemical clogging can result from precipitation of dissolved surface water constituents and may occur near the interface or anywhere along the flowpath. This is due to the change in geochemical conditions as infiltrating water enters the riverbed and aquifer. Factors to be considered when evaluating the potential for chemical clogging

include electrolyte concentration, pH, redox potential, presence of dissolved or colloidal organic matter, and the mineralogy and surface characteristics of stream bed and aquifer solids.

Finally, biological or microbial clogging can result from the accumulation of bacterial cells in pore spaces, the production of extra-cellular polymers, the release of gaseous byproducts from denitrifying bacteria and methanogens, and the microbially mediated accumulation of insoluble precipitates (Vandevivere et al., 1995; Baveye et al., 1998). Biogenic gas bubbles have the effect of blocking or partially blocking water flow through pores in much the same way that solid particles do (Orlob and Radhakrishna 1958; Oberdorfer and Peterson 1985; Sanchez de Lozada et al., 1994). Insoluble sulfide salts can cause clogging due to the activity of sulfate reducing bacteria, whereas iron hydroxide and manganese oxide deposition can be brought on by bacterial iron metabolism (Vandevivere et al., 1995; Baveye et al., 1998). Biological clogging is most likely to occur near the surface water - ground water interface where nutrients are most available.

Some or all of these processes may act at a particular site to lower hydraulic conductivity and thus decrease flow velocities. For example, several months of pumping from a new riverbank filtration well in Louisville, Kentucky resulted in a significant decline in well production, presumably due to a 70% reduction in leakance from the river to the adjacent aquifer. The reduced well yields were attributed to the physical clogging of riverbed sediments (Schafer, 2000). The disadvantage of reduced well yields accompanies the advantages of increased microbial inactivation rates due to lower flow velocities (and thus longer residence times in the aquifer) as well as increased removal of pathogens due to smaller pores.

4.3.1.3 Scour

Both the positive and negative effects of clogging on riverbank filtration system performance may be diminished following periodic flooding. Scour refers to the erosion of the river's bed and banks, and depends on both flood conditions and the resistance of the bed and bank material that has been deposited at a particular site. During flooding the river channel may be scoured, and fine sediments at the surface water - ground water interface mobilized.

Much of the removal of the contaminants and microbes discussed above occurs during the first few centimeters of the flow path, due to the significant filtering and sorptive capabilities of sediments in the riverbed. These sediments are often organic-rich, highly biologically active, and fine-grained. The effectiveness of bank filtration, however, may be temporarily threatened during high flows if this active layer is washed away or scoured. EPA suggests the potential for stream channel scour be evaluated during riverbank filtration site selection (section 4.4). Section 4.5 provides further discussion of scour and its implications for riverbank filtration system operation.

4.3.1.4 Additional Treatment Steps

In addition to clogging and scour, there are several disadvantages to bank filtration which utilities may wish to consider and balance against the advantages and cost savings described in section 4.3.1. One disadvantage is that an additional aeration step may be required during water treatment due to the possible depletion of oxygen as biological activity consumes oxygen during riverbank filtration pretreatment (Kuehn, et al., 2000). This oxygen depletion may lead to extremely anaerobic conditions over a portion of the flow path, which may sometimes result in the release of iron and manganese from the bank sediment into the flowing water. This process occurs due to a redox reaction which reduces iron and manganese to their water-soluble forms. This condition may necessitate the removal of these metals during subsequent treatment steps (Kuehn, et al., 2000; Tufenkji et al., 2002).

On the other hand, if the flow path between the riverbank and the well is long enough, iron and manganese may precipitate onto the sediments in the subsurface before ever reaching the well (Tufenkji et al., 2002). The aquifer becomes reaerated with increasing distance from the riverbed. This is one reason for locating riverbank filtration wells greater than 25 or 50 feet from the river, as discussed in section 4.5.2.2. Even though most contaminant removal occurs during the first few centimeters of subsurface transport, the reaeration and associated precipitation reactions in the aquifer may significantly improve water quality before it reaches the well (Tufenkji et al., 2002). The location of the aerated and anaerobic portions of the aquifer vary seasonally due to variable microbial activity and changing pumping rates.

Finally, riverbank filtration is ineffective at removing a few persistent compounds, primarily non-polar organic compounds and highly soluble chemical contaminants such as methyltertiarybutylether (MTBE) and trichloroethylene (TCE), which would need to be addressed during subsequent treatment steps. In addition, when bank filtration is used to induce infiltration of highly contaminated surface water, it may be important to include additional adsorption steps during later treatment (Kuehn, et al., 2000).

4.4 Site Selection and Aquifer Requirements

Unconsolidated, granular aquifers with sufficient amounts of fine-grained material (see section 4.4.2) are eligible for *Cryptosporidium* removal credits under the LT2ESWTR. Partially consolidated, granular aquifers may also be eligible for removal credits. Each granular aquifer proposed as a bank filtration site is to be evaluated on a case-by-case basis with regard to its grain size distribution and degree of cementation. For example, a partially consolidated, granular aquifer may be too cemented, and thus perhaps too fractured, to provide adequate pathogen removal. Geophysical methods, discussed in section 4.5.2.2, may be helpful in determining the degree of fracturing of such aquifers.

This section characterizes river and aquifer types that may be suitable for bank filtration surface water treatment. A list of selected sites in the United States and Europe which have used bank filtration

is provided for reference. No information is available for these sites, however, regarding whether they would meet the siting criteria in the LT2ESWTR. Some common aquifer types that are clearly not appropriate for this technology are described as well. Finally, site-specific aquifer criteria which shall be met in order for systems to receive *Cryptosporidium* removal credits are outlined in section 4.4.3.

4.4.1 Selected Bank Filtration Sites

Table 4.1 Selected Bank Filtration Systems in Europe and the United States

Site Location	Well Type*	Number of Wells	Maximum Capacity <i>mgd (m³/s)</i>	River System
Europe				
Torgau, Germany	V	42	39.7 (1.737)	Elbe
Mockritz, Germany	V	74	28.8 (1.260)	Elbe
United States				
Cincinnati, OH	V	10	40.0 (1.750)	Great Miami
Columbus, OH	H	4	40.0 (1.750)	Scioto/Big Walnut
Louisville, KY	H	1+	20.0 (0.875)	Ohio
Terra Haute, IN	H	1	12.0 (0.525)	Wabash
Jacksonville, IL	H	1	8.0 (0.350)	Illinois
Galesburg, IL	H	1	10.0 (0.438)	Mississippi
Henry, IL	V	1	0.7 (0.030)	Illinois
Mt. Carmel, IL	V	1	1.0 (0.044)	Wabash
Quincy, IL	H	1+	10.0 (0.438)	Mississippi
Sacramento, CA	H	1	10.0 (0.438)	Sacramento
Sonoma County, CA	H, V	5 (H) + 7 (V)	85.0 (3.727)	Russian
Independence, MO	H †	1	15.0 (0.656)	Missouri
Lincoln, NB	H, V	2 (H) + 44 (V)	35.0 (H) (1.530)	Platte
Kennewick, WA	H	1	3.0 (0.130)	Columbia
Kalama, WA	H	1	2.6 (0.110)	Kalama
St. Helens, OR	H	3	5.0 (0.219)	Columbia
Kansas City, KS	H	1	40.0 (1.750)	Missouri
Sioux Falls, OK	H	1+	40.0 (1.750)	Missouri

* H—horizontal, V—vertical

† Gravel-packed Laterals

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4.4.2 Aquifer Type

4.4.2.1 *Unconsolidated, Granular Aquifers*

Unconsolidated, granular aquifers can be composed of a wide range of sediment sizes including clay, silt, sand, and larger particles. They may also exhibit minor cementation, but subsurface samples are typically friable (readily crumbled by hand). To be eligible for bank filtration credits under the LT2ESWTR, unconsolidated granular aquifers are expected to contain a sufficient amount of fine-grained sediments to achieve adequate pathogen removal and/or inactivation (section 4.4.3 prescribes the amount deemed sufficient). In aquifers with these characteristics, the flow path is tortuous at the micro-scale (Figure 4.3), providing many opportunities for removal of microorganisms by straining or by their attachment to grain surfaces.

Many alluvial aquifers contain significant amounts of well-sorted, fine-grained sediments. Alluvial aquifers are produced by fluvial depositional processes and are adjacent to modern streams. Aquifers formed in glacial deposits may also contain sufficient amounts of fine-grained material. These may be “till” deposits, which have a wide range of poorly sorted sediment sizes, or glacial outwash deposits that are formed by meltwater and often contain well-sorted, sand-sized sediments. Any of these alluvial or till aquifers would be likely to be suitable for a bank filtration system. On the other hand, coarse gravel aquifers produced by the rapid drainage of glacial lakes, or in outwash environments that deposit little fine-grained material, may not be eligible for bank filtration credits unless sieve analysis shows sufficient fine-grained material as discussed in section 4.4.3.2.

Alluvial aquifers may be identified on detailed hydrogeologic maps simply as “Quaternary alluvium”, indicating both their genesis and relative age. Glacial deposits are documented on surficial geology maps and, where aquifer-forming, may be identified on large-scale hydrogeologic maps.

4.4.2.2 *Karst, Consolidated Clastic, and Fractured Bedrock Aquifers*

In karst, consolidated clastic, and fractured bedrock aquifers, ground water velocities are fast, and flow paths may be direct, allowing microbial contaminants to travel rapidly to a well with little removal or inactivation. Therefore, these aquifer types are not eligible for bank filtration treatment credits.

Karst may be broadly defined as a region where the dissolution of calcitic or other soluble bedrock, primarily limestone (calcium carbonate), produces a unique subsurface drainage network and associated surface landforms. Ground water movement in karst aquifers differs from that in porous, granular aquifers in that flow in the former occurs predominantly in conduits and dissolution-enlarged fractures. Consequently, there is little physical removal of microbes and other particles by filtration and few opportunities for microbes to come in contact with the surfaces of aquifer materials. Furthermore, rapid flow creates conditions where inactivation is less likely to occur before ground water reaches a well.

Although fractures have a role in ground water movement through any aquifer, fractures provide the dominant flow-path in fractured consolidated clastic and fractured bedrock aquifers. Most consolidated aquifers can be presumed to be fractured. Similar to solution conduits in karst aquifers, fractures in consolidated aquifers provide preferential flow paths that may transmit ground water at high velocities, and in a relatively direct flow path to a well, with little time or opportunity for inactivation or removal of microbial pathogens. Wells located in these aquifers would not be eligible for bank filtration credit.

4.4.2.3 Partially Consolidated, Granular Aquifers

Granular aquifers formed by marine processes earlier than Quaternary alluvial or glacial deposition may be partially consolidated by natural cement that fills pores, connects grains, and makes the aquifer material less friable. Partially consolidated, granular aquifers are present within the Atlantic Coastal Plain, Gulf Coast Lowland, Texas Coastal Upland, and Mississippi Embayment aquifer systems (USGS 1998). When significant proportions of cement are present, fractures are more likely to exist. As in consolidated aquifers, fractures in partially consolidated, granular aquifers create direct paths for microbial contamination that minimize the natural filtration capabilities of the aquifer system. EPA suggests that partially consolidated aquifers be evaluated at the proposed well location to determine if they may be too cemented, and thus perhaps too fractured, to provide sufficient natural filtration.

The degree of cementation can be evaluated by a variety of methods. Geologic material collected from below the aquifer's weathered zone that is friable upon touch is likely to be adequate for bank filtration purposes. Another test for the degree of cementation includes the slaking test, which involves alternate wetting and drying of the sample in water, or in salt or alcohol solutions. Finally, a triaxial compression test can be used to measure strain in three mutually perpendicular directions. Less cemented samples will be more deformable during such tests.

4.4.3 Aquifer Characterization

Systems seeking *Cryptosporidium* removal credit are required to characterize the aquifer properties between their surface water source and their well. The aquifer characterization will include, at a minimum, core sampling to determine grain size distribution. This data will establish whether enough fine-grained sediment is present to provide adequate filtration. The following procedure outlines the steps necessary to perform such a characterization, which will ultimately determine eligibility for bank filtration treatment credits under the LT2ESWTR.

- 1) Collect relatively undisturbed continuous core samples from the surface to a depth at least equal to the projected bottom of the well screen for the proposed production well.

- 2) Determine if recovered core consists of at least 90% of the interval from the surface to the planned location of the well screen bottom. If core recovery is insufficient, another well core must be obtained.
- 3) Examine each 2 foot long composite sample of recovered core in a laboratory using sieve analysis to determine grain size distribution. Core intervals are typically 2 feet long for a conventional split-spoon sampler and 3 or 4 feet long for soil probes (e.g., a Giddings-type soil probe).
- 4) If more than 10 percent of the sediments in each 2 foot long composite sample are *less than* 1.0 mm in diameter (very coarse sand), then the core interval from which it was taken is noted as containing a sufficient quantity of fine-grained material to provide adequate pathogen removal.
- 5) To receive *Cryptosporidium* removal credit, at least 90 percent of the analyzed composited core intervals from the sampled aquifer will meet criterion number (4) above.

4.4.3.1 Coring

The collection of relatively undisturbed cores in unconsolidated aquifers can be quite difficult, especially when gravel-sized clasts are present. The two most important criteria for successful test drilling to obtain a core are sample accuracy and drilling speed. Borehole stability is a major problem in drilling in an unconsolidated gravelly formation. Rotary core drilling is particularly suited to drilling in unconsolidated formations because the drilling fluid, which cools the drill bit and carries up the core, also acts to stabilize the borehole (Driscoll, 1986).

Other drilling methods require the installation of a casing to stabilize the borehole, a process which slows down the speed of drilling. Rotary core drilling is the fastest method for drilling in an unconsolidated formation. One disadvantage to rotary core drilling is the separation of different sized core particles as they rise (smaller particles rise faster) and cross-contamination by overlying borehole material. An experienced driller can avoid cross contamination by using the dual-wall method of rotary core drilling. In the dual-wall method, the core is pushed up the inner pipe of the drill rather than traveling in the space between the drill and the borehole wall (Driscoll, 1986). Shallow wells will have fewer particle size separation problems than deeper wells.

Auger drilling is another method for drilling test wells. In this method an earth auger is screwed into the earth by rotation. Auger drilling in an unconsolidated formation is slower than rotary core drilling, due to the necessary installation of casing to support the borehole. Sampling with augers can provide reliable samples from any depth. A split spoon sampler can be used wherein a split spoon is driven to the bottom of the hole. The depth to which an auger can drill is dependent on the size of the rig. The maximum drilling depth possible for a small drill rig is approximately 250 ft. (Driscoll, 1986).

Information about drilling and finding a driller can be found through the National Groundwater Association (NGWA) website: <http://www.ngwa.org/>. In addition, the EnviroDirectory™ provides listings for laboratories and drillers in New England, the Mid-Atlantic, and the Great Lakes regions (www.envirodirectory.com).

4.4.3.2 Sieve Analysis

The American Society for Testing and Materials (ASTM) has a published standard for conducting sieve analysis, the Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates: Standard C 136-1 (ASTM, 2003).

Sieve analysis is used to determine the particle size distribution of a sample of dry aggregate of known mass by passing the sample through a series of sieves with progressively smaller openings. Sieve analysis requires the following equipment:

1. A balance, accurate to 0.1g or 0.1% of test load for fine aggregate, or accurate to 0.5g or 0.1% of test load for a mixture of fine and coarse aggregate
2. Stackable sieves
3. A mechanical sieve shaker (for sample sizes greater than 20kg)
4. An oven capable of maintaining $110 \pm 5^{\circ}\text{C}$ ($230 \pm 9^{\circ}\text{F}$)

In the first step of sieve analysis the sample is dried using the oven. Once dry, its weight is measured and recorded. While the sample dries, sieves are selected with suitable openings to furnish the information required. For bank filtration related sieve analyses, it is only necessary to determine what percentage of the sample is less than 1.0mm; however, it is recommended that sieves covering a range of sizes be used so as to prevent the overloading of any one sieve. Once the sample is dry and the sieves are stacked in order of decreasing mesh size, the sample is placed in the top sieve and sieving either by machine or hand begins. Sieving should be continued until no more than 1% by mass of the material retained on an individual sieve will pass through that sieve during 1 minute of continuous hand sieving. Finally the mass on each sieve is weighed. The total mass of the material after sieving should correspond closely with the original mass of the sample. Using the mass for each size increment and the total mass of the sample, the size distribution of the sample can be determined (ASTM, 2003).

Further information about sieve analysis can be found at the ASTM web site (www.astm.org). A multi-media sieve analysis demonstration can be found at Geotechnical, Rock and Water Resources Library (GROW) (http://www.grow.arizona.edu/geotechnical/virtual_labs/sieveanalysis/sieveanalysisexp.shtml). ASTM also provides a search engine which allows the user to search for laboratories that perform sieve analyses (<http://astm.365media.com/astm/labs/>). The EnviroDirectory™ provides listings for laboratories and drillers in New England, the Mid-Atlantic, and the Great Lakes regions (www.envirodirectory.com).

4.4.4 Site Selection as it Relates to Scour

Stream channel scour may often be an important consideration in choosing sites that are suitable for riverbank filtration. This section discusses stream channel erosional processes in general, as well as reasons sites with certain characteristics may be unsuitable for riverbank filtration. Section 4.6 discusses the implications of periodic scour for riverbank filtration system operations. Detailed information on fluvial erosional processes can be obtained from any of a number of texts on fluvial geomorphology, hydrology, and river hydraulics (e.g., Leopold et al., 1964; Ritter et al., 1995; Chow 1964).

4.4.4.1 Stream Channel Erosional Processes

This discussion focuses on the dominant erosional processes of alluvial rivers because, given the LT2ESWTR's aquifer requirements, such rivers may be among the most suitable for bank filtration credits. Although many lake banks are also suitable sites for bank filtration, lakes will not be discussed in detail in this section. Lake bank filtration settings typically do not change rapidly with time and climate. Their hydrologic properties are not highly variable and thus do not require the detailed evaluation discussed here for riverbank filtration settings.

The width, depth, and gradient of an undisturbed alluvial river has typically adjusted to prevailing discharge conditions and sediment loads such that no net erosion or deposition occurs over long time periods (Mackin 1948; Leopold and Maddock 1953). The quasi-equilibrium condition of such rivers, which are referred to as "graded streams" (Mackin 1948), may be disrupted over short time periods (e.g., due to floods), when erosion or deposition may be considerable.

The dominant scouring process in alluvial rivers is lateral migration. This process is responsible for the stream meanders visible on many floodplains, and is accomplished by the progressive erosion of the outside bank of a river bend with concurrent deposition on the inside bank. Because erosion is generally matched by deposition in this process, channel dimensions do not change significantly over time, and the net result is migration of the channel across the floodplain (Figure 4.1). Stream channel meanders are characteristic of many alluvial rivers and are indicative of a graded stream.

Downcutting, another type of scour that can occur in fluvial environments, is the vertical erosion of the streambed. Downcutting is fairly uncommon in alluvial rivers except during floods or if the stream is not graded. The long-term dynamic equilibrium of a graded stream can be disrupted by a variety of changing hydrologic and geologic conditions and especially by anthropogenic activity. Human activities in a watershed or river channel may alter the conditions to which an alluvial river has become adjusted, initiating a period of readjustment marked by either progressive downcutting or aggradation (deposition).

Urbanization generally increases the proportion of impervious surface in a watershed, increasing flood volumes during precipitation events because less water is able to infiltrate the land surface and

recharge ground water (Jacobsen et al., 2001). Increased flood volumes may cause higher water levels in a river channel, increasing the shear stress on the channel bed and causing scour (Booth, 1990). Downcutting may continue until the channel gradient, and/or channel dimensions, become adjusted to the new flooding regime.

Impoundment is another activity that may disrupt the quasi-equilibrium state of a graded river and initiate readjustment of the channel. The sharp decrease in sediment supply, which commonly occurs subsequent to dam and reservoir construction, may initiate downcutting in the reach immediately downstream until the channel adjusts to the lightened sediment load. This has been observed downstream of many dams throughout the world. One of the most dramatic examples is the 7.5 meters of channel-bed degradation that occurred twelve kilometers downstream of the Hoover Dam after its completion in 1935 (Williams and Wolman, 1984).

The construction of artificial levees (raised banks along a stream channel) also may result in flooding downstream. Levees allow greater quantities of water to be carried by the stream, thus decreasing the probability of flooding in the vicinity of the levee, but increasing flood hazards downstream (Montgomery, 2000). Even if flooding downstream does not result, the high flows downstream may cause downcutting of the river, removal of fine-grained bed material, and thus a threat to the protectiveness of a riverbank filtration system. Another possible effect of levees is an increase in sedimentation in the channel. Sediment that would otherwise be deposited on the floodplain may be trapped within the channel. This can raise the channel bottom and thus raise stream stage or the elevation of the water surface in the channel (Montgomery, 2000). The consequences of this for a riverbank filtration system are variable. Increased sedimentation may lead to clogging and/or decreased well yields. On the other hand, higher stream stages may result in flooding and scour along certain portions of the river as the channel adjusts to a new equilibrium condition. Understanding the impact of current or planned upstream activities can be an important part of site selection for a riverbank filtration system.

4.4.4.2 Unsuitable Sites

As discussed in section 4.4.2.2, some sites may be ineligible for bank filtration credit due to the type of aquifer adjacent to the river. The following section, however, focuses on importance of understanding the nature of the surface water- ground water interface at a potential bank filtration site. In some localities, frequent scour, the absence of a sufficiently fine-grained interface, and/or the coarse-grained or fractured aquifer materials may suggest that a certain river or reach is not the best possible location for a bank filtration system. A system may choose to evaluate such situations on a site-by-site basis, however, except as specified in the LT2ESWTR, EPA does not require such evaluations or any particular decisions made on the basis of such evaluations. EPA recommends, however, that this information be considered in order to ensure that bank filtration systems are protective of public health.

Data from studies of aerobic and anaerobic spore (indicator organism) removal in bank filtration systems indicate that much of the removal of spores between a surface water body and a bank filtration pumping well takes place at the surface water–ground water interface and in the aquifer material proximal to that interface. The interface, which lines the bottom of the riverbed, is typically comprised of very fine-grained, biologically-active material a few inches to a foot in thickness. Some rivers, however, (especially many in the western United States) lack this fine-grained bed and the important organic-rich materials or silts usually associated with the surface water - ground water interface (Ray et al., 2002). For this reason, such rivers should be evaluated carefully to determine if bank filtration is a suitable treatment technology.

Other rivers may *sometimes* possess this important layer of fine-grained sediment for the first few inches or feet from the surface water source, but may at other times be subject to periodic scour. The nature and performance of the surface water–ground water interface on such rivers may be altered temporarily by flood scour, specifically during the high river stages that occur periodically throughout the year. This situation is most likely to occur on uncontrolled rivers. Higher flow velocities in the river and increased bedload transport at such times mobilizes fine sediments (which were deposited when discharges were lower). (Note that bedload transport is the carrying of heavy, coarse sediments by saltation along the stream bed rather than by suspension. Saltation is the process in which particles jump from one point to the next along the stream bed.) Lower log removals are thus expected to occur during floods. If such situations are expected to occur very frequently, and if a system cannot envision a way of managing the system so as to adequately protect its water supply during such events, sites on such rivers may be inappropriate for riverbank filtration. On the other hand, through careful management it may be feasible to protect drinking water wells from the potentially negative consequences of occasional scour, as discussed in section 4.6.2.

EPA recommends that the potential for scouring be considered during site selection. If a site that undergoes occasional scour is selected for riverbank filtration, the system may wish to locate its wells at greater than the required separation distance from the surface water body, as discussed in section 4.5.2.2. Such a solution helps to ensure the protection of public health. The drawback of this solution to the problem of scour, however, is that wells located at very great distances from surface water sources are drawing in more ambient ground water and less riverbank filtrate than wells located closer to the river or lake. One result of this is that the yield to the wells is likely to be smaller when the wells are located far from the surface water source.

The potential for scour can be evaluated initially by examining the past frequency of high flow and flood events. Data on flood history and discharge is typically available from the US Geological Survey, the Army Corps of Engineers, the US Bureau of Reclamation and the Department of Homeland Security (formerly FEMA). State and county highway and transportation departments typically evaluate river scour to determine the safety of bridge supports. A more comprehensive evaluation of the potential for scour can be conducted when the effect of past and current human activities (as discussed in section 4.4.4.1) is considered in comparison to the history of flood events.

Sources of high flow and flood data

USGS

Main Page: <http://water.usgs.gov>

The National Flood Frequency (NFF) Program:

<http://water.usgs.gov/pubs/wri/wri024168/pdf/entirereport.pdf>

- A computer program developed by the USGS for estimating the magnitude and frequency of floods for ungaged sites. Since 1993, updated equations have been developed by the USGS for various areas of the nation. These new equations have been incorporated into an updated version of the NFF Program.

USGS Fact Sheets (listed by state):

<http://water.usgs.gov/wid/index-state.html>

- Includes NFF program methods for estimating flood magnitude and frequency (in rural and urban areas) for: AL, AZ, AR, CA, CN, HI, LA, MD, MO, NV, NM, NC, OK, SC, SD, TX UT, VT, VA, and WA. These fact sheets describe the application of the updated NFF Program to various waterways within the specific State. Includes maps of each of the above state’s hydrologic regions, as well as regression equations and statistics.

WaterWatch:

http://water.usgs.gov/cgi-bin/dailyMainW?state=us&map_type=flood&web_type=map

- Map of current flood and high flow conditions in the United States. The map shows the location of streamgages where the water level is currently at or above flood stage (▲) or at high flow (●). The high flow conditions are expressed as percentiles that compare the current (i.e., within the past several hours) flow value to historical daily mean flow values for all days of the year. The real-time data used to produce the maps have not been evaluated or edited.

Army Corps of Engineers

Main Page: <http://www.usace.army.mil/>

- Flood control and management pages. For example, river and reservoir reports including flood level data are available for the St. Louis district of Missouri (see example below) (<http://mvs-wc.mvs.usace.army.mil/dresriv.html>).

Mississippi River:

River Mile	Gage Station	6 am Levels	24-hr Change	National Weather Service River Forecasr		Flood Level	Gage Zero	Record Level	Record Date	
				Next 3 Days	Crest Date					
309.0	Hannibal	16.9	- 0.2	16.6	16.1	15.6	16.0	449.3	31.80	07/10/93
301.2	Dam 22 tw	15.9	- 0.3	15.8	15.3	14.7	16.0	446.1	29.58	07/16/93

US Bureau of Reclamation

Main Page: <http://www.usbr.gov/main/>

Dams and Reservoirs Page: http://www.usbr.gov/dataweb/html/dam_selection.html

- The project DataWeb provides the most current information on the bureau’s projects, facilities, and programs including dam and reservoir information for western states. This data can be obtained by selecting a dam or from the State and Region maps.

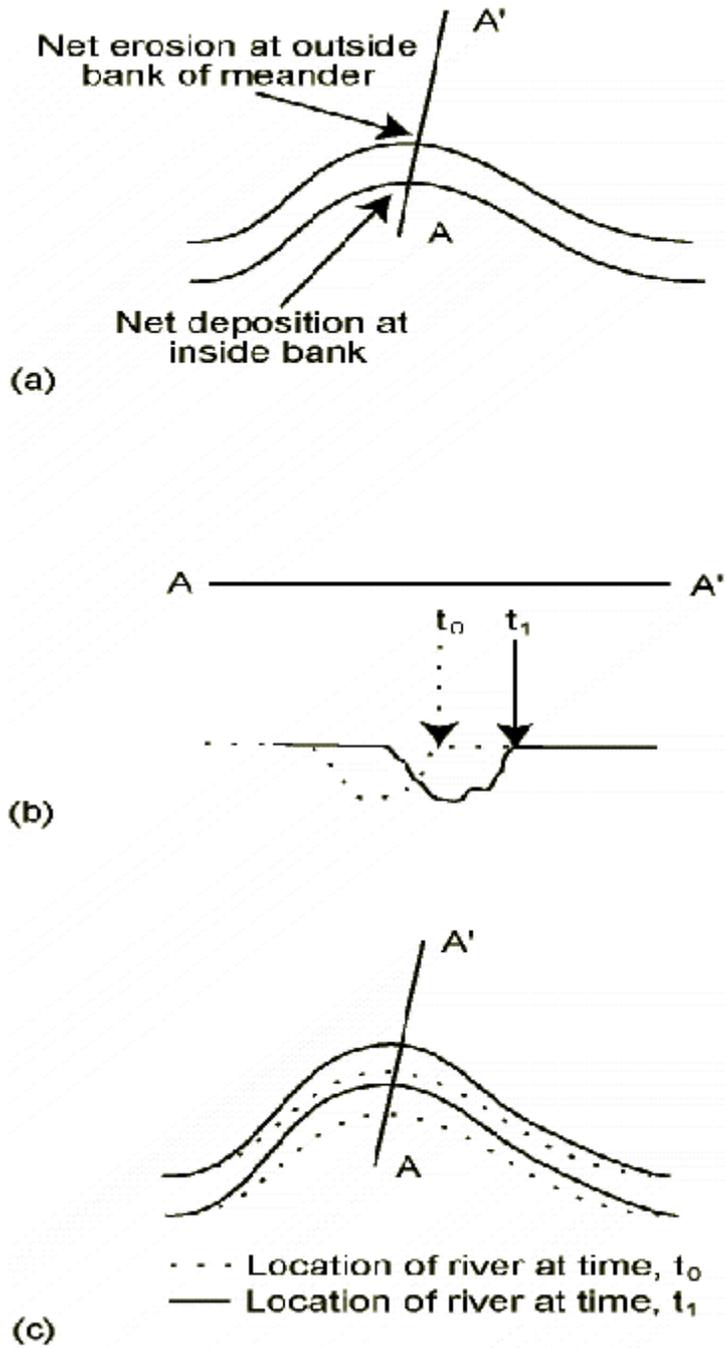
The Department of Homeland Security (formerly FEMA)

Main Page: <http://www.fema.gov/>

Flood Hazard Mapping: <http://www.fema.gov/fhm/>

- The flood maps describe where the flood risks are, based on local hydrology, topology, precipitation, flood protection measures such as levees, and other scientific data. Fee to obtain maps.

Figure 4.1 Generalized Depiction of Stream Channel Lateral Migration



(a) Map of a Stream Meander; (b) Cross-section of the Channel from A-A' with Channel Positions at 3 Successive Times (t_0 , t_1 , and t_2); (c) Map of Stream Meander Showing Location After Migration

4.5 Design and Construction

This section describes the type of wells eligible for bank filtration credits under the LT2ESWTR. Because specific well construction requirements (e.g., casing depths) vary by state and with geologic conditions, this guidance will address these issues only briefly where appropriate. Readers are referred to the agency within their state that makes regulations or recommendations regarding well construction for details on issues such as casing depths, annular seals, drilling methods, filter packs, etc. Other good general references on well construction include Driscoll (1986) and USEPA (1975).

Figure 4.2 Taking a Water Level Reading



The pump house for the horizontal collector well caisson is in the background.

4.5.1 Well Type

Only vertical and horizontal wells are eligible for bank filtration credits. Other types of ground water collection devices may not provide adequate filtration of pathogens. For example, a spring box is a ground water collection device located at the ground surface and is designed to contain spring outflow and protect it from surface contamination until the water is used. Spring boxes are found where local hydrogeologic conditions have focused ground water discharge into a smaller area (i.e., a spring) and at a faster volumetric flow rate than elsewhere. Often, localized fracturing or dissolution-enhanced channels are the cause of the focused discharge to the spring. As noted in section 4.4.2.2, fractures and dissolution channels have significant potential to transport microbial contaminants. Thus, spring boxes are not eligible for bank filtration credit.

Infiltration galleries (or filter cribs) are also not eligible for bank filtration credits. Infiltration galleries are designed to collect water infiltrating from the surface, or to intercept ground water flowing naturally toward surface water, using a slotted pipe installed horizontally in a trench and backfilled with granular material (Symons et al., 2000). An infiltration gallery is not bank filtration because the material overlying an infiltration gallery may be engineered to optimize oocyst removal. Bank filtration systems are defined as relying solely on the natural properties of the system to remove microbial contaminants. An infiltration gallery may, however, be eligible for *Cryptosporidium* removal credit as an alternative treatment technology [40 CFR 141.73(d)].

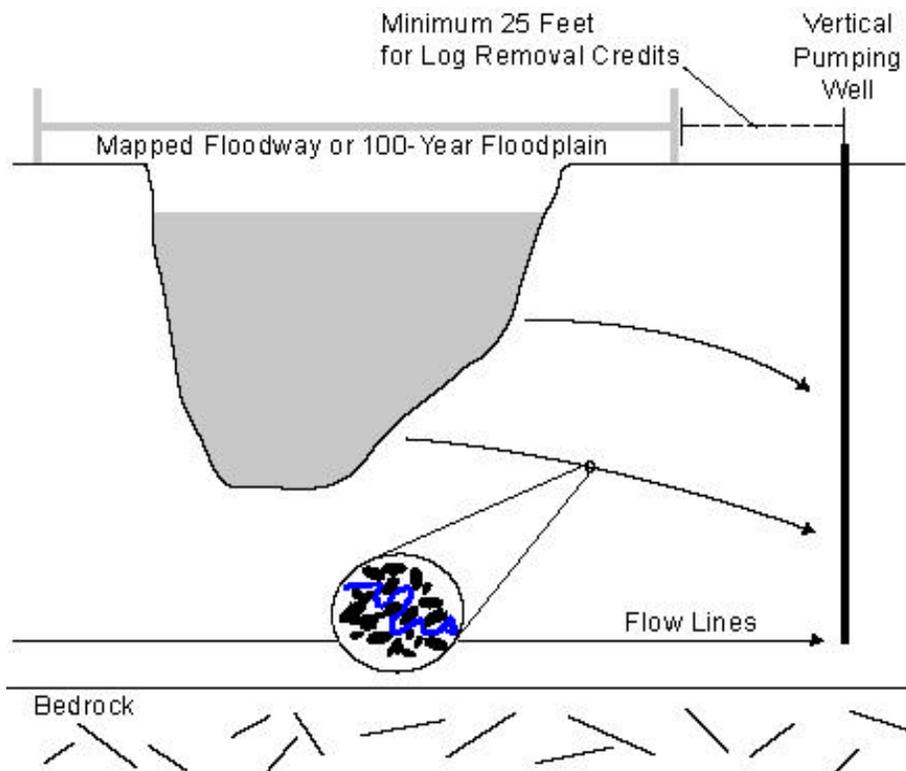
Horizontal and vertical wells are both eligible for bank filtration credits. They are distinguished from each other by the orientations of their well screens, and the important implications this has for their well hydraulics (Figure 4.3 and 4.4). Collector horizontal wells are constructed by the excavation of a central vertical caisson or pipe. One or more laterals (i.e., collector lateral well screens) extend horizontally from the caisson bottom and may be very long. Laterals may extend radially in all directions - resulting in a radial collector well- or primarily in the direction of the river (Driscoll, 1986; Ray, 2001a). The lateral well screens are often installed near the bottom of the formation, allowing a greater proportion of the saturated thickness of the aquifer to be used. A greater proportion of pathogens and other contaminants are removed when the distance between the surface water body and the laterals is increased (Ray, 2001a). Section 4.5.2.2 contains a discussion of when it may be appropriate to locate wells at separation distances greater than those required by the LT2ESWTR. Laterals may extend underneath a surface water body in the United States. This is generally not how horizontal wells are placed in Europe (Ray 2001a) because in Europe such wells are required to meet a 55-60 day average travel time requirement. An example of a pump house for a horizontal collector well in Louisville, KY is shown in Figure 4.2. It is elevated to prevent flood waters from entering it.

The choice between using a vertical or horizontal well for a bank filtration system depends on the site hydrogeology and the pumping requirements. For systems with large production requirements (e.g., many Public Water Systems) or for pumping in shallow alluvial aquifers, horizontal wells may be preferred because they are designed to capture large volumes of surface water recharge with little

drawdown (Driscoll, 1986). Vertical wells with large production requirements are not well suited to shallow alluvial aquifers because the necessary low drawdown cannot be sustained (Ray, 2001a).

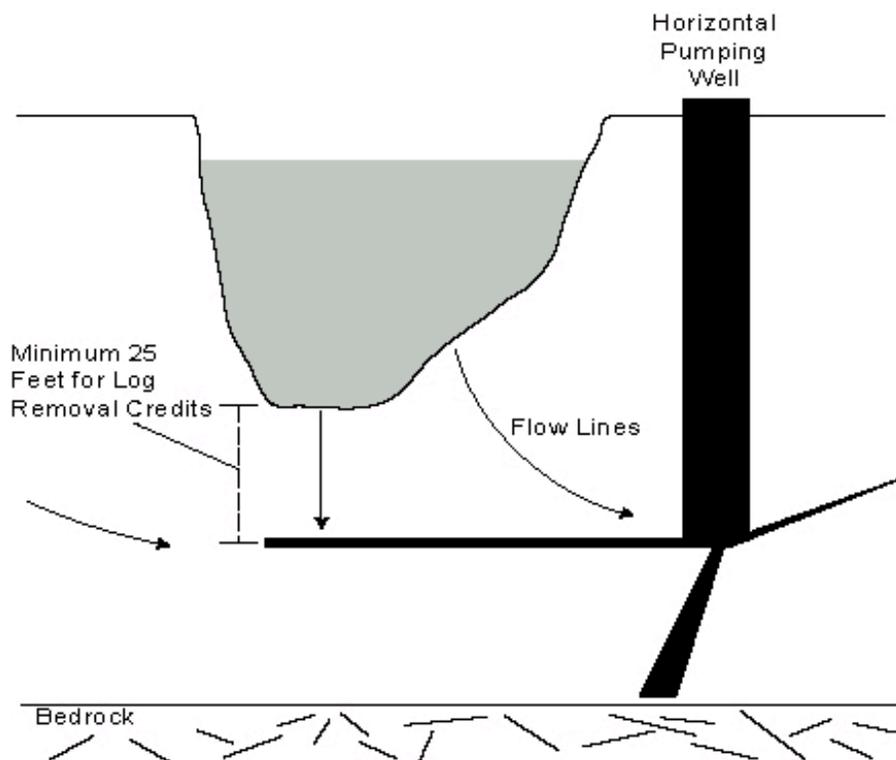
Finally, a comparison of construction expense with the costs of well maintenance may play a role in the choice of well type. Horizontal collector wells are substantially more costly than vertical wells (Driscoll, 1986). However, moderately large utilities may need many smaller capacity vertical wells to match the capacity of a horizontal well. The maintenance of these vertical wells may require significant effort and expense (Ray, 2001a). In such cases, horizontal collector wells may be preferred.

Figure 4.3 Schematic Showing Generalized Flow and Required Separation Distance to a Vertical Well



(Inset shows tortuous ground water flow at the micro-scale.)

Figure 4.4 Schematic Showing Generalized Flow and Required Separation Distance to a Horizontal Well With Three Laterals



4.5.2 Filtrate Flow Path and Well Location

For systems to receive *Cryptosporidium* log removal credits, the ground water flow path length between the edge of the surface water body and the well is expected to be sufficient for effective oocyst removal. This section discusses EPA's requirements for appropriate flow path lengths, and associated well locations, for the log removal credits available under the LT2ESWTR. The ground water flow path length necessary to receive credits is specified for both vertical and horizontal wells. A discussion of how to obtain information necessary to define the edge of the surface water body is also included.

4.5.2.1 Required separation distance between a well and the surface water source

Cryptosporidium oocyst removal may vary significantly throughout the year in many bank filtration systems. At most typical bank filtration locations, high log removal rates (e.g. 3.5 log removal

over 13 m) may be expected with the surface water discharges that predominate during most of the year. During short flood periods, however, there may be substantially lower removal (e.g. 0.5 to 1.0 log removal over 13 m) due to scouring of the surface water–ground water interface, as discussed below in section 4.6.2. In summary, a number of different factors may contribute to increased risk of *Cryptosporidium* reaching wells. These factors include the presence of coarse-grained aquifer or stream bed sediments, high river velocities, and frequent scouring of riverbeds. Given the need to protect water supplies during periods of high surface water discharge with their potentially lower log removal capabilities, the LT2ESWTR rule language (40 CFR 141.726(c)) provides 0.5 log removal credit for systems with bank filtration wells located greater than 25 feet from a surface water source and 1.0 log removal credit for wells located greater than 50 feet from a surface water source.

4.5.2.2 Locating wells at greater than required distances from the surface water source

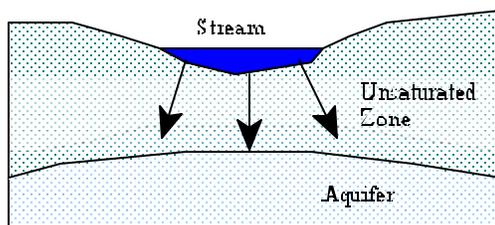
Given the dynamic nature of riverbanks and aquifer systems, including scouring processes, as discussed in section 4.3.1.3, it may sometimes be advisable to place bank filtration wells at distances greater than 25 or 50 feet from a surface water source. This extra precaution may also be advisable when a system is uncertain as to whether the riverbed and bank contain sufficient fine-grained material to provide adequate removal of *Cryptosporidium* oocysts. That is, EPA is requiring the separation distances of 25 feet and 50 feet for the log removal credits discussed above, but greater separation distances may result in additional public health protection at some sites. The disadvantage of using greater separation distances between the surface water source and the bank filtration well is that water yields to the well will be decreased. When a system makes a decision to place wells at a greater distance from a surface water source than EPA requires, it will need to balance the sacrifice in well yield with the added public health protection.

The remainder of section 4.5.2.2 discusses geophysical methods which may be of use in constructing a conceptual model of subsurface flow conditions in riverbank filtration systems. By obtaining hydrogeologic information through geophysical or other means (e.g., pre-existing hydrogeologic or geologic maps), systems can determine the degree to which local conditions may affect *Cryptosporidium* removal at the bank filtration site. For example, if mapping the bedrock-alluvial interface and the water table at a particular site indicates that the aquifer is fairly thin, it is unlikely that infiltrating river water will be diluted by much ambient ground water. In such a case it may be advisable to locate wells at greater than the required distance from the surface water source. On the other hand, if detailed hydrogeologic investigations indicate that the aquifer contains a large proportion of fine-grained sediments, it would not be advisable to locate the well at greater than the required distance from the surface water source, because the aquifer is already likely to be an efficient pathogen filter, and it would be inadvisable to further sacrifice well yields.

When the aquifer contains fine-grained material, it is possible that well over-pumping may break the hydraulic connection between ground water and surface water, yielding a variably saturated zone underneath a perched stream, as shown below in Figure 4.5. Formation of such a variably saturated

zone during periods of high pumping can greatly alter the existing ground water flow paths. New ground water flow paths could result in marked changes in water quality. For example, surface water infiltration could occur further upstream, resulting in a longer ground water flow path for infiltrating surface water flowing towards the well. The increase in flow path-length could improve water quality. Alternatively, the result of over-pumping could be decreased water quality. This may occur because the decreased thickness of the saturated aquifer - due to the formation of a large variably saturated zone - may cause faster ground water flow (assuming pumping rates remain constant). Faster ground water flow provides less time for contaminant attenuation within the aquifer. Finally, the variably saturated zone itself, to the extent that it transmits water, can improve water quality because contaminant attenuation is usually increased under variably saturated conditions. If possible, the potential for formation of a variably saturated zone can be investigated in order to provide additional information regarding the desirability of locating wells at greater than required distances from the surface water source.

Figure 4.5 The Streambed of a Perched Stream Is Well above the Water Table



Geophysical methods generally do not disturb subsurface materials. They are often less expensive than labor-intensive digging of trial pits or drilling of boreholes. Furthermore, the useful information gleaned by using geophysical methods can aid in choosing the best locations for wells (Reynolds, 1997). Geophysical methods include gravity and magnetic methods, seismic methods, electrical methods, and ground penetrating radar.

Hydrogeophysical methods can be used in pre-existing boreholes, thereby providing high resolution data for a very localized area around the borehole. Alternatively, surface geophysical methods can be used to obtain more generalized information over a large area, including information on the depth to the water table, the depth to bedrock, and stratigraphy (Hubbard, 2003). The discussion below provides only a generalized overview of currently available geophysical methods. More detailed information can be obtained from texts by Hearst (2000), Reynolds (1997), Rubin and Hubbard (2003), Keys (1990) and Burger (1992).

Gravity surveying measures variations in the acceleration due to the Earth's gravitational field which are caused by density variations in subsurface rocks. Subsurface cavities can be detected with this technology, however sites with such cavities would not be suitable for bank filtration. Reynolds (1997) states that gravity methods are fairly uncommon in hydrogeological work compared to electrical methods. On the other hand, in the Arizona district of the United States Geological Survey, gravity methods have been in use for over 15 years to evaluate changes in water storage in aquifers. These methods can detect water table elevation changes of as little as a few inches (Callegary, 2003). Thus, gravity methods may be useful at riverbank filtration sites for assessing the depth to water table, aquifer thickness, and seasonal effects on the dilution of infiltrating river water with ambient groundwater. Magnetic surveying or magnetic anomalies can also be used in hydrogeologic investigations. For example, clay infilling bedrock cavities can be detected due to slight changes in the magnetic susceptibility of clay and most bedrock (Reynolds, 1997).

Seismic methods are widely used in hydrogeologic investigations. Applied seismology involves generating a signal through an explosion or other method at a specific time. The generated seismic waves travel through the subsurface, are reflected and refracted back to the surface, and the return signals are detected on monitoring instruments. The amount of time that elapses is the basis for determining the nature of subsurface layers/materials (Reynolds, 1997). Reynolds (1997) provides a detailed example of the use of seismic refraction surveying for locating the bedrock/alluvial interface at one particular site.

Seismic methods can be used to:

- estimate depth to bedrock (ideal for riverbank filtration applications)
- determine the nature of bedrock (e.g., cavernous) or location of cavities. Note that karst buried by alluvium may contain unexpected ground water flowpaths.
- determine the location of faults that may juxtapose bedrock against alluvial material
- determine stratigraphy (useful where sands and clays may be interlayered)
- determine porosity
- determine ground water particle velocities (an important parameter for riverbank filtration systems)

Electrical resistivity methods are used extensively in downhole logging to identify hydrogeologic units that will produce high flow rates. Electrokinetic surveying makes use of electrodes implanted at the ground surface to identify the location of the water table. This may be useful at riverbank filtration sites, where water table layer and depth to bedrock can be used to determine aquifer thickness - an important parameter in determining how much dilution of bank filtrate with ambient groundwater is occurring. A more recent development is the use of electrokinetic methods to measure flowrates in boreholes (Reynolds, 1997).

The spontaneous polarisation or self-potential (SP) method is conducted by measuring differences in ground electrical potential at different locations, but is still fairly uncommon. Another

electrical method, the induced polarisation (IP) method can be used to detect ground water and water tables, however electromagnetic induction methods are generally considered more practical for these purposes in the field. Contaminated ground water within subsurface clays can also sometimes be detected with the IP method (Reynolds, 1997).

Electromagnetic (EM) methods have been used in groundwater investigations to delineate contaminant plumes, and thus can be useful in conceptualizing flow systems in a riverbank filtration context when the quality of infiltrating river water is especially poor. Pulse-transient EM (TEM) surveys (a type of EM method) may be useful in conceptualizing flow for riverbank filtration systems where infiltrating water quality is poor. It may also be useful in monitoring the quality of infiltrating water.

When data is available from both borehole and surface instruments, EM and electrical methods can be used to map subsurface geology such as the locations of coarse-grained and fine-grained units.

Ground penetrating radar (GPR) has been used as a surface method for contaminant plume mapping and monitoring pollutants in groundwater. To operate such a system, a signal generator, transmitting and receiving antennae, and a receiver must be used. Radiowaves are generated, which travel in a broad beam at high speeds. Energy is lost or attenuated depending on the subsurface materials through which the waves travel. GPR has proven valuable in mapping sediment sequences, and can be used to investigate sediments through freshwater up to 27 m deep (Reynolds, 1997). Thus, it may be of use in gaining information about the composition of riverbeds, and for monitoring the effects of scour on riverbed composition. GPR can also be used to locate water tables, delineate sedimentary structures which may contain pockets of coarse-grained alluvium, and determine the spatial extent and continuity of buried clay and peat layers within subsurface deposits. Borehole radar can also be used for hydrogeologic investigations.

Before choosing a specific geophysical method it may be important to consider the following: desired level of resolution, area of coverage, site-specific conditions and their influence on the applicability of the method, possible non-uniqueness of the geophysical attribute, resources needed to interpret the geophysical data, and possible integration with direct measurements. In general, mapping the water table and finding the depth to bedrock are considered standard hydrogeophysical procedures. Other applications such as estimating permeabilities or porosities are at an earlier stage of development and may not yet be appropriate for routine use at riverbank filtration sites (Hubbard, 2003).

4.5.2.3 Delineating the edge of the surface water source

The flow paths due to induced infiltration to a vertical well have both vertical and horizontal components, and are tortuous at the micro-scale (Figure 4.3). Such flow will typically have a significant horizontal component, especially if the vertical well is screened in a shallow, unconsolidated, alluvial aquifer that is eligible for bank filtration credits. Therefore, for the purpose of receiving log removal credits, the flow path length to a vertical well is to be determined using the measured horizontal distance

from the edge of the surface water body to the well intake. The edge of the surface water body is defined as the edge of either the 100-year floodplain or the floodway, discussed below. The 100-year floodplain is defined by its boundary - the flood elevation that has a one percent chance of being equaled or exceeded each year.

As a first step, utilities may use the online maps available at the following website to get a general idea of the mapped extent of the 100-year floodplain in their area: <http://www.esri.com/hazards/makemap.html>. In order to satisfy the requirements of the LT2ESWTR for the location of the wells of a bank filtration system, however, an official Federal Emergency Management Agency (FEMA) (now part of the Department of Homeland Security) flood hazard map must be used. Such maps can be ordered in either paper or digital formats from FEMA. The following website can be used to order these maps: <http://msc.fema.gov/MSC/>.

Although in some areas of the United States the mapped extent of the 100-year floodplain may be more easily accessible than the mapped extent of the floodway, some utilities may choose to use the edge of the floodway as a starting point for measuring separation distances to wells because it typically allows wells to be placed slightly closer to the river and is thus a somewhat less restrictive requirement. The floodway is a regulatory concept, and is defined as that portion of the overbanks that must be kept free from encroachment to discharge the one percent annual chance flood (i.e. the 100-year flood) without increasing flood levels by more than 1.0 foot. It is determined by specified methods according to FEMA guidelines, as described below.

For many areas, the mapped extent of the floodway will also be drawn on the flood hazard map obtained by FEMA. The utility may choose to use the edge of the floodway rather than the edge of the 100-year floodplain for the purpose of determining the required separation distance between a river and a riverbank filtration well. If the mapped extent of the floodway is unavailable, the utility may opt to perform the mapping using one of a number of hydraulic models approved by FEMA. A list of these approved models is available at http://www.fema.gov/mit/tsd/en_hydra.htm. EPA recommends using the US Army Corps of Engineers' HEC-RAS model for mapping floodway limits. The HEC-RAS software, User's Manual, Applications Guide, and Hydraulic Reference Manual are available for free downloading from http://www.hec.usace.army.mil/software/software_distrib/index.html.

When a utility elects to determine the edge of the floodway, and to model the floodway boundaries if they are not available from FEMA, the preferred encroachment method within HEC-RAS is Method 4. Method 4 can be summarized as follows, according to FEMA's Map Assistance Center (2003):

The Method 4 encroachment operates by analyzing the hydraulic conveyance for the unencroached one percent annual chance floodplain at each cross section, then equally reducing the conveyance from both overbank areas by moving toward the stream channel from the edge of the floodplain until the resulting water-surface elevation is one foot higher than the unencroached elevation, and the resulting encroached conveyance is approximately equal to the unencroached conveyance. The

new left and right cross-section limits are assumed to be vertical walls. Finally, a backwater energy balance is calculated using the new cross sections, which results in the encroached or floodway water-surface profile. The floodway modeling process requires adjustments and rerunning of the model because the final calculation is the backwater energy balance between new cross sections. Many times the 1.0-foot target cannot be achieved exactly at each cross section because of energy balance considerations. Floodplain geometry, constrictions at culvert and bridge crossings, and constrictions from other man-made obstructions in the floodplain may require adjustments to the encroachment widths to stay at or below the 1.0-foot maximum water-surface increase. Chapter 10 of the HEC-RAS User's Manual includes a discussion of performing a floodway encroachment analysis.

In most areas, however, EPA expects that utilities will find it preferable and simpler to use the previously mapped limits of the 100-year floodplain to determine the edge of the river for riverbank filtration separation distances.

4.5.2.4 Measuring separation distances for horizontal wells and wells that are neither horizontal nor vertical

As noted in section 4.5.1, horizontal wells may have laterals that extend underneath a surface water body. The flow direction for induced infiltration to a horizontal well that extends under a surface water body is predominately downward. Therefore, the flow path length to a horizontal well is the measured vertical distance from the bed of the river under normal flow conditions to the closest horizontal well lateral's intake (Figure 4.4).

Some wells may be constructed so that the well is neither truly horizontal nor truly vertical. In these cases, there is greater uncertainty about the definition of separation distance from surface water. For simplicity, if the well is closer to being a vertical well than to being a horizontal well (i.e. the well is oriented at greater than a 45 degree angle to a horizontal line), the separation distance is defined for the purposes of this toolbox option to be the horizontal distance from the edge of the river to the closest (in terms of horizontal distance) intake on the well. Similarly, if the well is closer to being a horizontal well as opposed to a vertical well, separation distance is defined as the shortest possible vertical distance from the riverbed to an intake on the well. To ensure that the assigned log removal credit is realized, systems are expected to perform continuous turbidity monitoring for all wells that receive a credit. Continuous turbidity monitoring is discussed in section 4.2.2.

4.6 Operational Considerations

4.6.1 High River Stage

When the river stage (i.e. the elevation of the water surface) is high, the increased head gradient between the river and the adjacent aquifer results in increased infiltration and increased ground water

flow rates. This condition can be expected to occur periodically throughout the year at many sites, and will generally be associated with reduced log removals (Gollnitz, 1999; Ray, 2001b). High river stage is often associated with scouring of riverbed sediments. Nevertheless, even when scour does not occur, the high ground water velocities associated with high river stage can be a significant threat to a riverbank filtration system.

One solution to this problem is that pumping rates can be temporarily decreased during periods of high river flow (Medema et al., 2000). Decreased pumping rates will in turn decrease the head gradient between the river and the well, thereby decreasing subsurface velocities, increasing residence times, and facilitating pathogen inactivation.

4.6.2 Implications of Scour for Bank Filtration System Operations

Periodic, short-term flood scour can have both negative and positive impacts on the performance of a bank filtration system. As noted in section 4.5.2 above, lower log removals of oocysts are expected during floods because higher river shear velocities and associated increases in bedload transport mobilize fine sediments deposited when discharges were lower.

Removal of fine sediments opens large pore spaces, increasing the hydraulic conductivity across the surface water–ground water interface (Gollnitz, 1999; Ray, 2001a; Ray, 2001b). Unfortunately, this potentially increases the number of pathogens transported. Furthermore, the microbial activity and unique geochemical environment of the riverbed, which serves to facilitate the removal of pathogens via sorption and other processes, may not be present for short periods following flood scour. Recent work in Germany (Baveye et al., 2003) suggests that the biologically active zone is re-established very quickly after scour, perhaps within 3 days, at least when measured in terms of the ability to degrade certain organic compounds. Limited scour can reduce clogging at the surface water–ground water interface and improve well yields (Wang et al., 2001). The continuous turbidity monitoring required by the LT2ESWTR for bank filtration credits can be used to help systems manage the threat posed by periodic, short-term flood scour.

When high river stages or high turbidity levels indicate that flood scour may be occurring and compromising the effectiveness of a bank filtration system, pumping rates can be decreased. This will lead to lower velocities and longer subsurface residence times, thereby increasing the protectiveness of the system (Medema et al., 2000; Juhasz-Holterman, 2000).

4.6.3 Anticipating high flow events / flooding

Many factors are involved in increasing the probability that a flood will occur. Intense rainfall is the most apparent factor, however the geomorphology of a watershed is important in determining how quickly water will enter a stream system after a rainfall event, as well as how quickly water will enter a

major river from smaller tributaries. Systems can anticipate that a high flow event will occur if a rapid spring thaw follows a winter of unusually heavy snowfall. It is also important to be aware of recent changes in vegetation due to wildfires or urbanization. When vegetation is removed or decreased there are fewer barriers to rapid surface runoff, plant roots no longer keep soil loose and permeable (thus more compact soils will be less able to decrease surface runoff), and plants themselves will be unavailable to take in a certain proportion of precipitation (Montgomery, 2000). Therefore, systems may wish to monitor for pathogens more frequently or change pumping regimes in riverbank filtration systems when high flows are anticipated.

4.6.4 Possible responses to spill events and poor surface water quality

One response to a serious water quality threat is to stop pumping from all bank filtration production wells. Other pumping regime changes can also be implemented to reduce risks, including decreasing the number of hours the system is in operation each day. For systems that have a number of wells in operation, it may be advisable to increase pumping rates for wells further from the surface water source and decrease pumping rates for wells that are closer (Juhasz-Holterman, 2000). Juhasz-Holterman (2000) recommended that this kind of change be implemented seasonally at a site in the Netherlands. Her study of the site's hydrology indicated that during the winter months pumping wells were more vulnerable to contamination due to "short-circuited" flow paths from the polluted river through the subsurface. Her solution involved both restricting extraction rates to a few hours a day (which was acceptable due to decreased demand during the winter months) as well as an altered pumping regime which relied more on wells located further from the river.

4.6.5 Maintaining required separation distances

Alluvial rivers that are experiencing active, progressive erosion as an adjustment to new flooding regimes or sediment loads, or in relation to natural lateral migration, may pose serious, longer-term challenges to bank filtration systems. For example, significant log removal reductions may be more frequent in an urbanizing basin as a consequence of more frequent flooding and associated scouring. In extreme cases, long term degradation of the bed or banks may reduce the threshold separation distances between the surface water source and bank filtration well. Recall that these separation distances - 25 feet for 0.5 log removal credit and 50 feet for 1.0 log removal credit - are required to receive log removal credits under the LT2ESWTR.

Systems may wish to assess their sites for active, progressive erosion. Lateral migration rates can be calculated using sequential aerial photography and/or topographic maps, if available. Systems without such data may need to obtain the needed information by conducting sequential field surveys of the floodplain area proposed for the site. This will require a far more lengthy investigation period. Progressive downcutting could also be measured with sequential field surveys of the channel bed

elevation over a period of years. Regardless of the method used, the threshold separation distances between the surface water source and the bank filtration well must be maintained.

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5.0 Presedimentation

5.1 Introduction

Presedimentation is a preliminary treatment process used to remove gravel, sand, and other material from the raw water and dampen particle loading fluctuations to the rest of the treatment plant. This toolbox option is applicable to new sedimentation basins only; systems with existing presedimentation basins that are required to conduct source water monitoring for *Cryptosporidium* must collect samples after the basins for the purposes of bin classification (40 CFR 141.726(a)).

Sedimentation processes are common in the water treatment process and much design and operational information is available. However, the use of an additional sedimentation basin in series, or a pre-sedimentation basin at the head of the treatment plant is not as common as the standard sedimentation basin, and little information is available. Therefore, the guidance provided in this chapter is based on the design and operational principles of sedimentation processes.

This chapter on presedimentation is organized as follows:

- 5.2 LT2ESWTR Compliance Requirements - This section describes the criteria presedimentation basins must achieve in order to receive *Cryptosporidium* removal credit.
- 5.3 Toolbox Selection Considerations - This section assists systems in determining whether the presedimentation toolbox option is a viable and beneficial option for meeting the LT2ESWTR bin requirements.
- 5.4 Types of Presedimentation Basins - This section compares several sedimentation basins and clarifiers in terms of structure and factors affecting settling efficiency.
- 5.5 Design and Operating Issues - This section discusses typical design and operational issues including redundancy, short circuiting, sludge removal, and coagulant addition.

5.2 LT2ESWTR Compliance Requirements

5.2.1 Credits

Presedimentation basins with coagulant addition may receive 0.5 log *Cryptosporidium* removal credit under the LT2ESWTR if they meet the following criteria (40 CFR 141.726(a)):

- The presedimentation basin must be in continuous operation and must treat all of the flow reaching the filters.
- A coagulant must be continuously added to the presedimentation basin (or prior to) while the plant is in operation.
- The presedimentation basin must achieve 0.5 log (68 percent) turbidity reduction on an average monthly basis, for at least 11 of the 12 previous months. For those systems not operating year-round, the 0.5 log turbidity reduction must be met for all but any one of the operating months, based on the last 12 consecutive months.

Systems with existing presedimentation basins **must** monitor for *Cryptosporidium* after the presedimentation basin and prior to the main treatment plant for the purpose of determining bin assignment and **cannot receive presedimentation credit** towards *Cryptosporidium* removal to meet the bin requirements (40 CFR 141.704(b)).

5.2.2 Monitoring Requirements

Systems must measure presedimentation basin influent and effluent turbidity at least once per day, or more frequently as determined by the State (40 CFR 141.726(a)).

5.2.3 Calculations

For compliance with the LT2ESWTR, the log turbidity reduction must be calculated as a monthly mean, from readings collected daily, according to the following equation (40 CFR 141.726(a)).

Log Reduction =

$\text{Log}_{10}(\text{Monthly Average Influent Turbidity}) - \text{Log}_{10}(\text{Monthly Average Effluent Turbidity})$

Or if calculated as a percent,

Percent Reduction =

$$\frac{(\text{Monthly Average Influent Turbidity}) - (\text{Monthly Average Effluent Turbidity})}{(\text{Monthly Average Influent Turbidity})} \times 100$$

Example Calculation

Average influent turbidity = 16.3 NTU

Average effluent turbidity = 4.2 NTU

$$\text{Log Reduction} = \text{Log}_{10}(16.3) - \text{Log}_{10}(4.2) = 0.59$$

$$\text{Percent Reduction} = (16.3 - 4.2) / 16.3 = 74.2\%$$

5.3 Toolbox Selection Considerations

The purpose of this section is to assist systems in determining whether the presedimentation toolbox option is a viable and beneficial option for meeting the LT2ESWTR bin requirements. There are two general aspects for systems to evaluate when considering this toolbox option:

- 1) Can the turbidity removal requirements be met consistently over the expected range of raw water conditions?
- 2) What are the advantages and disadvantages of installing a presedimentation basin?

For presedimentation, the first question is driven by source water particle load and how much of that load a proposed sedimentation basin would remove. Before researching potential presedimentation designs, a system should determine if their source water has a high enough turbidity on a consistent basis. Section 5.3.1 discusses the source water characteristics necessary to meet the compliance requirements. Section 5.3.2 discusses the advantages and disadvantages of adding a presedimentation process to the treatment train.

5.3.1 Source Water Quality

To meet the 0.5 log turbidity removal requirement, the source water should have consistently high turbidity. When influent turbidity is low, most presedimentation basins will have difficulty achieving 0.5 log reduction. For example, if a system has an average of 10 NTU source water turbidity for a few months of the year, the average effluent turbidity would have to be 3.2 NTU for those months, which could be difficult for some systems to achieve. Table 5.1 lists influent and effluent turbidity values that yield 0.5 log reduction.

Table 5.1 Influent and Effluent Turbidity Values Resulting in 0.5 Log Reduction

Monthly Average Turbidity (NTU)		Monthly Average Turbidity (NTU)	
Influent	Effluent	Influent	Effluent
2	0.6	50	15.8
5	1.6	60	19.0
10	3.2	70	22.1
20	6.3	80	25.3
30	9.5	90	28.5
40	12.6	100	31.6

5.3.2 Advantages and Disadvantages of Installing a Presedimentation Basin

The presedimentation process can reduce influent fluctuations in particle loading, flow, and other water quality parameters. An additional sedimentation process in series provides increased operational flexibility to handle rapid changes in influent turbidity. It also allows for enhanced performance of subsequent processes in the treatment plant. Although, if the presedimentation effluent turbidity is too low, the second sedimentation process may not be able to provide significant removal since removal performance is enhanced by increased particle load.

As with the addition of many unit processes, the two major disadvantages are capital costs and land requirements. The requirement of coagulant addition may increase chemical costs, although the amount added in the next stage could be reduced. Whether these chemical costs offset each other is site-specific.

5.4 Types of Sedimentation Basins

There are several types of sedimentation basins (also called clarifiers) used for drinking water treatment. Selection of a basin for presedimentation should be based on turbidity removal capability and meeting the flow and space requirements of the facility. The focus of this chapter is on guidance for complying with the LT2ESWTR, therefore the discussion in this section is limited to factors affecting settling efficiency, as measured by turbidity removal. Further information on design can be found in the following literature:

- *Water Quality and Treatment—A Handbook of Community Water Supplies, 5th ed.* (AWWA 1999)
- *Integrated Design and Operation of Water Treatment Facilities, 2nd ed.* (Kawamura 2000)

Table 5.2 provides a comparison of several sedimentation basins and clarifiers. It is likely that only horizontal clarifiers would be chosen for presedimentation, since they are less complex in operation compared to the others (i.e., upflow, high rate, reactor, and ballasted sand clarifiers). The table includes the additional types since some plants that choose to employ the presedimentation toolbox option may elect to use their current sedimentation basin for presedimentation and construct a new basin for primary sedimentation. The performance advantages and disadvantages listed in the table relate to settling efficiency or indications for potential process upset. These were derived from *Integrated Design and Operation of Water Treatment Facilities* (Kawamura 2000) and are characteristic of sedimentation processes, not specifically presedimentation processes. The remainder of this section provides short descriptions of different clarifier types.

Table 5.2 Comparison of Sedimentation and Clarifier Types

Type	Performance Advantages	Performance Disadvantages
Applicable for Presedimentation and Sedimentation		
Horizontal Flow (general)	-Easy to operate and maintain	
Rectangular Basin	-Tolerant to shock loads -Good for handling large flows	-Subject to wind and density currents (causing short-circuiting) -Designs with trays have shown poor settling efficiency
Circular Basin	-Easy sludge removal -Can obtain high clarification efficiency	-Greater potential for hydraulic imbalance in comparison to rectangular basin (not good for removing alum flocs)
Applicable for Sedimentation		
Upflow Clarifier (general)	-High clarification efficiency	-Need constant flow rate and water quality -Limitations on size
Center Feed	-Easy sludge removal	-Short circuiting
Peripheral Feed	-Good for source water with high solids	-Potential short-circuiting
High Rate Settlers (horizontal flow or upflow)	-Increases the hydraulic load capability and settling efficiency of horizontal flow basins and clarifiers	-Can form scales (calcium carbonate) which clog flow -Poor flocculation possible
Reactor Clarifiers (general)	-Good clarification due to seeding effect	-Need constant flow rate and water quality -Requires greater operator skill
High recirculation and mechanical sludge plow	-Tolerant to shock loads	-Dependent on one drive unit -Limitations on size
Sludge blanket zone and mechanical sludge plow	-Good turbidity removal	-Very sensitive to shock loads -Requires 2-4 days to build sludge blanket
Ballasted sand	-Can handle higher flows with very low detention times (on the order of minutes) -Can handle shock particle loads without increasing coagulant dose -Quick process startup	-Short detention time means not much time for process adjustments

Note: Adapted from "Integrated Design and Operation of Water Treatment Facilities." Kawamura (2000).

Sedimentation processes can be categorized in three general types: horizontal flow basins or clarifiers, upflow clarifiers, and reactor clarifiers. High rate settlers are modified horizontal or upflow clarifiers with plate or tube modules placed into the basin to increase the settling area. An additional design described in this chapter that differs from the three general types is ballasted sand or high-rate microsand process (a proprietary design).

5.4.1 Horizontal Flow

5.4.1.1 Rectangular

In rectangular sedimentation tanks the water flows in one end and ideally proceeds through the basin in a plug flow manner. A uniform distribution at the inlet is an important design factor. Rectangular basins can be susceptible to density currents that cause short circuiting. These basins are easy to operate, have low maintenance costs, offer predictable performance under most conditions, and are most tolerant to shock loads. High rate settlers can be easily installed to improve settling efficiency. Rectangular basins are particularly well suited for large systems compared to circular basins that require additional space and yard piping for equivalent flow.

5.4.1.2 Circular

The flow in circular basins is more commonly from a center feed well, radially outward to the peripheral weirs. In comparison to rectangular basins, circular basins will have more land between the basins and also require more yard piping. Circular basins have easy sludge removal, can obtain high clarification efficiency, and are adaptable to high rate settling modules. However, if flow distribution from the inlet is not uniform, the settling efficiency will be hindered. These basins are not as hydraulically stable as rectangular basins.

5.4.2 Upflow Clarifier

In upflow clarifiers the influent enters at the bottom and clarified water flows upward while the solids settle to the bottom. As with horizontal flow basins, upflow clarifiers can also be modified with high rate settling modules. Upflow clarifiers can provide higher clarification efficiency than horizontal flow, however, they are more sensitive to shock loads than horizontal flow basins.

5.4.3 Reactor Clarifier

Reactor clarifiers use the seeding concept to improve settling. The water flows through the sludge layer so particles can coalesce with already formed flocs. Two common designs of reactor

clarifiers are slurry recirculation and sludge blanket clarifiers. Both operate on a center feed system with built-in flocculation zones. The process is more complex than traditional horizontal or upflow clarifiers. Reactor clarifiers can provide high clarification efficiency but at the cost of flexibility—the source water quality and hydraulic loads must be constant.

5.4.4 High Flow Rate Designs

High rate settlers are modules of inclined tubes or plates that are installed in horizontal flow (plates only) or simple upflow clarifiers. They provide increased surface area for particles to settle and reduce settling time. Kawamura (2000) noted poor performance occurred when flow distribution was uneven and flocculation was poor.

5.4.5 Ballasted Flocculation

Ballasted flocculation is a high-rate, physical-chemical clarification process that uses sand to improve the settling of flocculated particles. The floc attaches to the surface of a sand particle, which has a settling time 20 to 60 times faster than an alum floc (Kawamura 2002), thus creating a high-rate settling process. Because of the increased settling rate, the space required is much less than other clarifiers.

5.5 Design and Operational Issues

5.5.1 Redundancy

As stated earlier, for compliance with the LT2ESWTR, all flow must be treated by the presedimentation process to receive *Cryptosporidium* treatment credit (40 CFR 141.726(a)). Systems should consider the need for redundancy in the design of a presedimentation process. Smaller systems or systems with a demand much lower than the design capacity may be able to shut down the water treatment plant for presedimentation basin maintenance activities and, thus, not require additional basins for redundancy. However, systems that operate on a continuous basis do not have that flexibility and should have a plan for staying in compliance while a basin is shut down.

5.5.2 Short Circuiting

A common issue that must be considered in the design and operation of presedimentation basins is short-circuiting. If a portion of flow does not receive close to the intended treatment (in this case, detention time), then the effluent turbidity is likely to be higher than anticipated. Several factors

affect short-circuiting including even distribution of flow at the inlet, density or temperature differentials between influent and basin water, surface currents, and basin cleaning and sludge removal.

A proper design of the inlet is one of the most important design factors. In addition to flow short-circuiting, a poorly designed inlet can lead to overall hydraulic instability in the settle zone. Installation of perforated baffles is a simple and effective method for even flow distribution from the inlet to the basin.

Temperature differentials and high wind velocities could induce circular currents in the vertical direction of the basin. Influent water warmer than the basin water will rise to the surface and reach the outlet of the sedimentation basin much faster than the intended detention time of the basin. Influent water colder than the basin water will dive to the bottom of the basin and flow along the bottom of the basin and rise to the top of the basin at the outlet, thereby reaching the outlet of the sedimentation basin much faster than the intended detention time of the basin. Above ground tanks built of steel are more susceptible to temperature differentials from exposure to the sun and heat transfer.

The degradation of effluent water quality due to wind is more noticeable in circular or square sedimentation basins of diameters greater than 100 – 115 feet. When using long, shallow rectangular settling basins, effects of wind induced currents can be minimized by ensuring that the longitudinal axis of the basin is perpendicular to the prevailing wind direction. In addition to causing flow short-circuiting, currents can also scour settled solids, causing resuspension of settled solids and increasing effluent turbidity.

5.5.3 Sludge Removal

Sludge build-up in the tank decreases the volume of the sedimentation basin and reduces the settling time in the basin. Additionally, as sludge builds up, particles become more susceptible to resuspension during sludge removal, increasing the effluent turbidity. Sedimentation basins with high rate settlers accumulate sludge rapidly, and therefore require continuous sludge removal.

5.5.4 Coagulant Addition and Dose Ranges of Common Coagulants

Current operational practice of presedimentation processes often focus on mitigating shock loads in the raw water supply (such as turbidity spikes due to precipitation in river source waters). However, during periods of low influent turbidity less attention may be given to the actual performance of the basin, resulting in less than 0.5 log turbidity reduction through the basin. To receive the credit, the presedimentation basin may need to be operated more stringently, including the addition of coagulant. The coagulant dose required to treat an influent stream depends on the chemical composition of the influent, the characteristics of the colloids and suspended matter in the influent, the addition of a

coagulant aid, the water temperature, and mixing conditions. Coagulant dose and other water chemistry parameters of the coagulation and sedimentation processes are system-specific. Jar test procedures for evaluating the appropriate coagulants, dosages, and other chemical attributes for a treatment train are provided in AWWA's *Operational Control of Coagulation and Filtration Processes*.

References

AWWA. 2000. Operational Control of Coagulation and Filtration Processes, AWWA Manual M37, Second Edition, pp. 1-34.

Kawamura, Susumu. 2000. *Integrated Design and Operation of Water Treatment Facilities*. John Wiley & Sons, Inc.

USEPA. 1998. Optimizing Water Treatment Plant Performance Using the Composite Correction Program, pp. 233-236.

6.0 Lime Softening

6.1 Introduction

Lime softening is a drinking water treatment process that uses chemical precipitation with lime and other chemicals to reduce hardness and to enhance clarification prior to filtration. Lime softening can be categorized into two general types: (1) single stage softening that is used to remove calcium hardness and (2) two-stage softening that is used to remove magnesium hardness and high levels of calcium hardness. A single stage softening plant includes a primary clarifier and filtration components. A two stage softening plant has an additional clarifier located between the primary clarifier and filter. Within these general categories there are several possible treatment schemes; however, describing each is beyond the scope of this chapter.

This toolbox option is practical for lime softening plants that either have a two stage process or could upgrade to a two stage process. The advantage of using this toolbox option to achieve compliance with the LT2ESWTR is that systems will have the treatment process in place or if an upgrade or modification is needed, it could benefit the treatment of other contaminants. A disadvantage for softening plants is a potential reduced flexibility in the treatment train since all water must be treated by both stages.

Since the water systems considering this toolbox option will most likely have a lime softening process in place, this section does not provide design or operational information. Instead, this section focuses on the requirements that lime softening systems must meet to receive *Cryptosporidium* removal credit and how those requirements can be met with general process modifications. The chapter is organized into two sections:

- 6.2 LT2ESWTR Compliance Requirements - describes the criteria that plants must meet in order to receive additional credit for *Cryptosporidium* removal, and reporting requirements to maintain compliance.
- 6.3 Split Flow Processes - addresses compliance issues for split flow processes.

6.2 LT2ESWTR Compliance Requirements

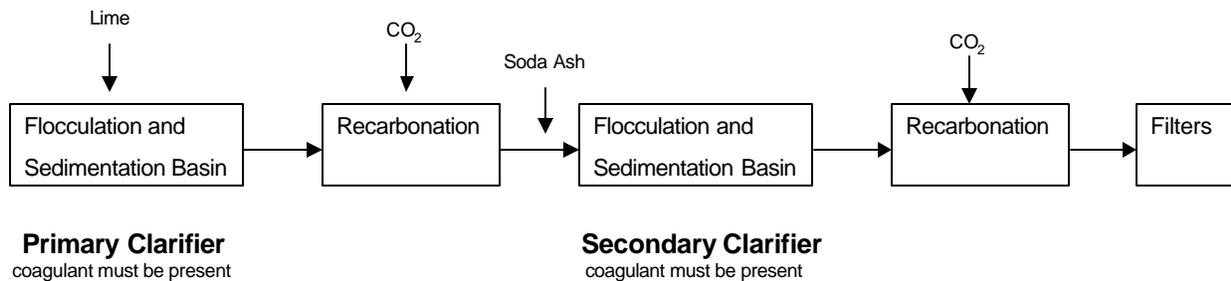
6.2.1 Credit for *Cryptosporidium* Removal

The LT2ESWTR requires plants to meet the following criteria in order to receive 0.5 log credit towards additional *Cryptosporidium* treatment requirements (40 CFR 141.726(b)):

- The plant must have a second clarification step between the primary clarifier¹ and filter which is operated continuously. For split treatment processes, only the portion of flow going through two clarification stages can receive credit. If a portion of flow bypasses one stage, additional treatment must be provided to the bypassed portion (see section 6.3).
- A coagulant must be present in both clarifiers. Precipitation of metal salts (e.g., magnesium hydroxide or excess lime) could be considered a coagulant for the second clarifier.

Figure 6.1 shows a typical two stage lime softening process. Lime or lime and soda ash are added at the first stage. To receive treatment credit for this type of process, both stages of clarification must have a coagulant present.

Figure 6.1 Typical Two-Stage Lime Softening Process



¹ For purposes of compliance with the lime-softening toolbox option, “clarifier” is used as a general term for processes with settling.

6.2.2 Reporting Requirements

The LT2ESWTR requires monthly verification and reporting of the following conditions for systems using the lime softening option (40 CFR 141.730):

- Continuous operation of a second clarification step between the primary clarifier and filter
- Continuous presence of coagulant in the first and second stage clarifiers
- Both clarifiers treat 100 percent of the plant flow

In addition, EPA recommends submitting a schematic of the treatment process to the State, clearly identifying the two stages of clarification. EPA also recommends that systems monitor the coagulant dosages (or concentration) in the secondary clarifier on a daily basis, for the first year, and record the average and minimum coagulant concentrations. This data can assist the State in assessing whether the system operates in compliance at all times.

6.3 Spilt-Flow Processes

Split-flow processes divert a portion of the flow from either the first or second stage of the process and then blend the two streams together further downstream. Only the portion of flow that receives the two stages of treatment would be eligible for the 0.5 log credit. In these situations, systems would either have to: 1) eliminate the bypass and direct the entire flow through both stages, or 2) treat the bypassed portion with another toolbox option, such as chlorine dioxide, membranes, or ozone to receive 0.5 log credit for that stream.

7. Combined and Individual Filter Performance

7.1 Introduction

Turbidity is an optical property that measures the amount of light scattered by suspended particles in a solution. It can detect a wide variety of particles in water (e.g. clay, silt, mineral particles, organic and inorganic matter, and microorganisms), but cannot provide specific information on particle type, number, or size. Therefore, the U.S. Environmental Protection Agency (EPA) recognizes that turbidity reduction is not a direct indication of pathogen removal, but is an effective indicator of process control.

The Surface Water Treatment Rule (SWTR), Interim Enhanced SWTR (IESWTR), and Long Term 1 Enhanced SWTR (LT1ESWTR) all motivate public water systems to achieve a certain level of finished water quality by requiring them to meet specified filtered water turbidity limits. Under the IESWTR and LT1ESWTR, combined filter effluent turbidity in conventional and direct filtration plants must be less than or equal to 0.3 NTU in 95 percent of samples taken each month and must never exceed 1 NTU. These plants are also required to conduct continuous monitoring of turbidity for each individual filter, and provide an exceptions report to the State or regulating agency when certain criteria for individual filter effluent turbidity are exceeded.

The LT2ESWTR awards additional *Cryptosporidium* treatment credit to certain plants that maintain finished water turbidity at levels significantly lower than currently required. This credit is not available to membrane, bag/cartridge, slow sand, or diatomaceous earth plants, due to the lack of documented correlation between effluent turbidity and *Cryptosporidium* removal in these processes.

This remainder of this chapter is organized as follows:

- 7.2 LT2ESWTR Compliance Requirements - describes the conditions for receiving *Cryptosporidium* removal credit and monitoring requirements for maintaining compliance.
- 7.3 Reporting Requirements - describes the routine reporting requirements that systems must follow to receive credit.
- 7.4 Process Control Techniques - discusses modifications or operational aspects that provide the tightened process control needed to meet the turbidity requirements for this toolbox option.
- 7.5 Process Management Techniques - describes standard operating procedures, response plans for loss of chemical feed, adequate chemical storage, and voluntary programs that encourage full process control from administration to operation and maintenance.

7.2 LT2ESWTR Compliance Requirements

7.2.1 Treatment Credit

For systems using conventional or direct filtration treatment to obtain an additional 0.5 log *Cryptosporidium* removal credit, the LT2ESWTR requires the combined filter effluent (CFE) turbidity measurements taken for any month at each plant are less than or equal to 0.15 NTU in at least 95 percent of the measurements (40 CFR 141.727(a)).

Alternatively, the LT2ESWTR allows systems using conventional or direct filtration treatment to claim an additional 1.0 log *Cryptosporidium* removal credit for any month at each plant that meet both of the following individual filter effluent (IFE) turbidity requirements (40 CFR 141.727(b)):

- 1) IFE turbidity must be less than 0.1 NTU in at least 95 percent of the maximum daily values recorded at each filter in each month, excluding the 15 minute period following return to service from a filter backwash

AND

- 2) No individual filter may have a measured turbidity greater than 0.3 NTU in two consecutive measurements taken 15 minutes apart.

Systems may not claim credit for combined filter performance AND individual filter performance in the same month (40 CFR 141.727(a)).

7.2.2 Monitoring Requirements

For both the CFE and IFE options, compliance with the LT2ESWTR is determined by sample measurements taken for the IESWTR and LT1ESWTR (40 CFR 141.727(a) and (b)). In other words, the LT2ESWTR does not require any additional monitoring from the IESWTR and LT1ESWTR.

7.2.2.1 Combined Filter Effluent

The monitoring frequency and compliance calculation requirements for the CFE option are that CFE turbidity must be measured at 4-hour intervals (or more frequently) and 95 percent of the measurements from each month must be less than or equal to 0.15 NTU (40 CFR 141.727(a)).

7.2.2 Individual Filter Effluent

The monitoring frequency and compliance calculation requirements for the IFE option are that IFE turbidity must be measured every 15 minutes (excluding the 15 minute period following return to service from a filter backwash) and 95 percent of the measurements from each month must be less than or equal to 0.1 NTU (40 CFR 141.727(b)).

The LT2ESWTR specifies no individual filter may have a measured turbidity greater than 0.3 NTU in two consecutive measurements taken 15 minutes apart (40 CFR 141.727(b)). If the individual filter is not providing water which contributes to the CFE (i.e., it is not operating, is filtering to waste, or its filtrate is being recycled) the system does not need to report the turbidity for that specific filter.

7.2.3 Turbidity Monitors

An important aspect of awarding additional removal credit for lower finished water turbidity is the performance of turbidimeters in measuring turbidity below 0.3 NTU. The EPA believes that currently available turbidity monitoring equipment is capable of reliably assessing turbidity at levels below 0.1 NTU, provided instruments are well calibrated and maintained. EPA strongly recommends systems that pursue additional treatment credit for lower finished water turbidity to develop the procedures necessary to ensure accurate and reliable measurement of turbidity at levels of 0.1 NTU and less, and believes these procedures to be essential to maintain toolbox credit.

Turbidimeter maintenance should include frequent calibration by the manufacturer's methods as well as frequent verification, in order to measure accurately in the low turbidity ranges required for this toolbox option. Chapter 3 of the *LT1ESWTR Turbidity Provisions Guidance Manual* describes the sampling methods, operation, maintenance, and calibration for turbidimeters and discusses quality assurance and quality control measures. This section summarizes the information from that chapter, including the approved methods, commonly used turbidimeters, calibration standards, and important factors of maintaining turbidimeters. Systems are encouraged to review Chapter 3 of the *LT1ESWTR Turbidity Provisions Guidance Manual* to ensure their operation, maintenance, and calibration practices meet or exceed those recommended by EPA.

[insert web address for LT1 Guidance Manual]

7.2.3.1 Methods

Currently, EPA has approved three methods for the measure of turbidity (described in 40 CFR 141.74).

- EPA Method 180.1
- Standard Method 2130B
- Great Lakes Instrument Method 2

These methods are summarized in Appendices C, D, and E of the *LTIESWTR Turbidity Provisions Guidance Manual*.

7.2.3.2 Maintenance and Calibration

Maintenance and calibration of both benchtop and on-line turbidimeters are fully described in the *LTIESWTR Turbidity Provisions Guidance Manual*. It is very important to follow the manufactures procedures for maintenance and calibration of turbidimeters, as they vary between manufacturers. Tables 7.1 and 7.2 list several maintenance and calibration activities common among manufacturers for on-line and bench top turbidimeters. These activities should be conducted for all turbidimeters to ensure proper operation on a consistent basis.

Table 7.1 Maintenance and Calibration Activities for On-line Turbidimeters

Activity	Recommended Frequency
Inspect for cleanliness	Weekly
Verify sample flow rate	Weekly
Verify calibration with primary standard, secondary standard or by comparison with bench-top ¹	For CFE credit: Weekly on CFE turbidimeter and monthly on all IFE turbidimeters
	For IFE credit: Weekly on both CFE and IFE turbidimeters
Clean and calibrate with primary standard	Quarterly ²
Verify alarm settings and response to alarms	Quarterly
Replace lamp	Annually

¹The sampling and comparative process of using a bench top turbidimeter is likely to introduce unacceptable levels of error into the verification process. Therefore, EPA recommends using a primary or secondary standard over the bench top for calibration.

²Frequency should be increased if verification indicates greater than a +/-10 percent deviation from secondary standard.

Table 7.2 Maintenance and Calibration Activities for Bench Top Turbidimeters

Activity	Recommended Frequency
Inspect for cleanliness	Daily
Verify calibration with secondary standard	Weekly
Clean and calibrate	Quarterly ¹
Replace lamp	Annually

¹Frequency should be increased if verification indicates greater than a +/-10 percent deviation from secondary standard.

In addition to those activities listed in the tables, the following documentation or record keeping items should be developed and kept up to date.

- Log of turbidimeter maintenance and calibration
- QA/QC plan for accuracy and consistency
- Standard operating procedures

7.2.3.3 Quality Assurance / Quality Control (QA/QC)

Systems should develop a QA/QC plan for measuring turbidity. This plan should include written standard operating procedures (SOPs) to ensure that operation, maintenance, and calibration activities are carried out in a consistent manner, and that each activity is understood by all that are involved. At a minimum, systems should develop SOPs for cleaning turbidimeters, creating Formazin Standards, calibrating turbidimeters, and referencing index samples.

For bench top turbidimeters, measurement errors can be introduced by dirt, scratches, or condensation on the glassware, air bubbles in the sample, and particle settling. Operators should strictly follow manufactures procedures for sampling and maintenance.

7.3 Reporting Requirements

7.3.1 Combined Filter Performance

In order to receive the 0.5 log removal credit for the LT2ESWTR, a water system must submit monthly verification of CFE turbidity levels less than or equal to 0.15 NTU in at least 95 percent of the 4-hour CFE measurements taken each month (40 CFR 141.730).

7.3.2 Individual Filter Performance

For the 1.0 log removal credit under the LT2ESWTR, a water system must report monthly verification of IFE turbidity levels less than or equal to 0.1 NTU in at least 95 percent of all maximum daily IFE measurements taken each month for each filter (excluding the 15 minute period following startup after backwash), and monthly verification that there were no IFE measurements greater than 0.3 NTU in two consecutive readings 15 minutes apart for any filter (40 CFR 141.730).

As requirements of the IESWTR and the LT1ESWTR, water systems must report monthly that they have conducted individual filter turbidity monitoring. Systems are required to report actual IFE

measurements only if they have exceeded one of the IFE turbidity triggers. Systems that would apply successfully for the 1.0 log *Cryptosporidium* removal credit for LT2ESWTR compliance would not, by definition, be systems that were required to report IFE measurements under the earlier regulations. A system must, therefore, submit additional information about IFE turbidity measurements in order to receive the 1.0 log credit.

7.4 Process Control Techniques

To meet the lower finished water turbidity requirements, systems will need a high level of process control from the source water intake to the filters. The *Guidance Manual for Compliance with the IESWTR: Turbidity Provisions* (EPA 1999) discusses many design and operational aspects water systems should consider for achieving low effluent turbidity. Chapter 4 of that manual provides design and operational modifications systems can use to optimize their process for compliance with the LT2ESWTR toolbox requirements. This chapter of the Toolbox Guidance Manual builds on that information, by highlighting those modifications or operational aspects that provide the tightened process control needed to meet the turbidity requirements for this toolbox option. To meet the lower finished water turbidity requirements of the CFE or IFE performance standards, systems will need consistent process performance and the ability to maintain the high filtered water quality under sub-optimal conditions and changing water quality.

The IESWTR guidance manuals are available on EPA's website at:

www.epa.gov/safewater/mdbp/implement.html

Design and operational factors are not the only considerations for maintaining the high filtered water quality standards; all areas of a water system must be dedicated towards the process optimization goal, including administration and maintenance. This toolbox option will require continuing effort and commitment from management and operations staff. Table 7.3 lists several factors in the areas of administration, design, operation, and maintenance that may limit a system's ability to continually meet the LT2ESWTR lower finished water turbidity requirements. This table demonstrates the importance of considering the capabilities of the entire water system. This table was adapted from the Composite Correction Program, an EPA program for optimizing water treatment plant performance (discussed in section 7.5.4.2).

**Table 7.3 Performance Limiting Factors
(Adapted from the Composite Correction Program)**

ADMINISTRATION	
Plant Administrators	
Policies	Do existing policies or the lack of policies discourage staff members from making required operation, maintenance, and management decision to support plant performance and reliability?
Familiarity with Plant Needs	Do administrators lack first-hand knowledge of plant needs?
Supervision	Do management styles, organizational capabilities, budgeting skills, or communication practices at any management level adversely impact the plant to the extent that performance is affected?
Planning	Does the lack of long range planning for facility replacement or alternative source water quantity or quality adversely impact performance?
Complacency	Does the presence of consistent, high quality source water result in complacency within the water utility?
Reliability	Do inadequate facilities or equipment, or the depth of staff capability, present a potential weak link within the water utility to achieve and sustain optimized performance?
Source Water Protection	Does the water utility lack an active source water protection program?
Plant Staff	
Number	Does a limited number of staff have a detrimental effect on plant operations or maintenance?
Plant Coverage	Does the lack of plant coverage result in inadequate time to complete necessary operational activities? (Note: This factor could have significant impact if no alarm/shutdown capability exists - see design factors).
Personnel Turnover	Does high personnel turnover cause operation and maintenance problems that affect process performance or reliability?
Compensation	Does a low pay scale or benefit package discourage more highly qualified persons from applying for operator positions or cause operators to leave after they are trained?
Work Environment	Does a poor work environment create a condition for "sloppy work habits" and lower operator morale?
Certification	Does the lack of certified personnel result in poor O&M decisions?
Financial	
Operating Ratio	Does the utility have inadequate revenues to cover operation, maintenance, and replacement of necessary equipment (i.e., operating ratio less than 1.0)?
Coverage Ratio	Does the utility have inadequate net operating profit to cover debt service requirements (i.e., coverage ratio less than 1.25)?
Reserves	Does the utility have inadequate reserves to cover unexpected expenses or future facility replacement?

DESIGN	
Source Water Quality	
Microbial Contamination	Does the presence of microbial contamination sources in close proximity to the water treatment plant intake impact the plant's ability to produce an adequate treatment barrier?
Unit Process Adequacy	
Intake Structure	Does the design of the intake structure result in excessive clogging of screens, build-up of silt, or passage of material that affects plant equipment?
Presedimentation Basin	Does the design of an existing presedimentation basin or the lack of a presedimentation basin contribute to degraded plant performance?
Raw Water Pumping	Does the use of constant speed pumps cause undesirable hydraulic loading on downstream unit processes?
Flow Measurement	Does the lack of flow measurement devices or their accuracy limit plant control or impact process control adjustments?
Chemical Storage and Feed Facilities	Do inadequate chemical storage and feed facilities limit process needs in a plant?
Flash Mix	Does an inadequate mixing result in excessive chemical use or insufficient coagulation to the extent that it impacts plant performance?
Flocculation	Does a lack of flocculation time, inadequate equipment, or lack of multiple flocculation stages result in poor floc formation and degrade plant performance?
Sedimentation	Does the sedimentation basin configuration or equipment cause inadequate solids removal that negatively impact filter performance?
Filtration	Do filter or filter media characteristics limit the filtration process performance?
Disinfection	Do the disinfection facilities have limitations, such as inadequate detention time, improper mixing, feed rates, proportional feeds, or baffling, that contribute to poor disinfection?
Sludge/Backwash Water Treatment and Disposal	Do inadequate sludge or backwash water treatment facilities negatively influence plant performance?
Plant Operability	
Process Flexibility	Does the lack of flexibility to feed chemicals at desired process locations or the lack of flexibility to operate equipment or processes in an optimized mode limit the plant's ability to achieve desired performance goals?
Process Controllability	Do existing process controls or lack of specific controls limit the adjustment and control of a process over the desired operating range?
Process Instrumentation /Automation	Does the lack of process instrumentation or automation cause excessive operator time for process control and monitoring?
Standby Units	Does the lack of standby units for key equipment cause degraded process performance during breakdown or during necessary preventive maintenance activities?
Flow Proportioning	Does inadequate flow splitting to parallel process units cause individual unit overloads that degrade process performance?

Alarm Systems	Does the absence or inadequacy of an alarm system for critical equipment or processes cause degraded process performance?
Alternate Power Source	Does the absence of an alternative power source cause reliability problems leading to degraded plant performance?
Laboratory Space and Equipment	Does the absence of an adequately equipped laboratory limit plant performance?
Sample Taps	Does the lack of sample taps on process flow streams prevent needed information from being obtained to optimized performance?
OPERATION	
Testing	
Process Control Testing	Does the absence or wrong type of process control testing cause improper operational control decisions to be made?
Representative Sampling	Do monitoring results inaccurately represent plant performance or are samples collected improperly?
Process Control	
Time on the Job	Does staff's short time on the job and associated unfamiliarity with process control and plant needs result in inadequate or improper control adjustments?
Water Treatment Understanding	Does the operator's lack of basic water treatment understanding contribute to improper operational decisions and poor plant performance or reliability?
Application of Concepts and Testing to Process Control	Is the staff deficient in the application of their knowledge of water treatment and interpretation of process control testing such that improper process control adjustments are made?
Operational Resources	
Training Program	Does inadequate training result in improper process control decisions by plant staff?
Technical Guidance	Does inappropriate information received from a technical resource (e.g., design engineer, equipment representative, regulator, peer) cause improper decision or priorities to be implemented?
Operational Guidelines/Procedures	Does the lack of plant-specific operating guidelines and procedures result in inconsistent operational decision that impact performance?
MAINTENANCE	
Maintenance Program	
Preventive	Does the absence or lack of an effective preventive maintenance program cause unnecessary equipment failures or excessive downtime that results in plant performance or reliability problems?
Corrective	Does the lack of corrective maintenance procedures affect the completion of emergency equipment maintenance?
Housekeeping	Does a lack of good housekeeping procedures detract from the professional image of the water treatment plant?
Maintenance Resources	

Materials and Equipment	Does the lack of necessary materials and tools delay the response time to correct plant equipment problems?
Skills or Contract Services	Do plant maintenance staff have inadequate skills to correct equipment problems or do the maintenance staff have limited access to contact maintenance services?

7.4.1 Chemical Feed

There are two main considerations for the chemical application of a coagulation and flocculation treatment process:

- Are the chemicals and their dose optimum for the treatment process?
- Are they properly mixed or dispersed at the right point in the system?

7.4.1.1 Type of Chemical and Dose

Optimizing the coagulation and flocculation for the range of water quality and demand experienced by the plant is a key factor in improving the overall treatment performance and ensuring process control. One method commonly used to evaluate the type and dose of coagulant and other chemical additives is the jar test (AWWA 2000a).

To provide the process control necessary for producing consistently low filter water turbidity, systems should establish SOPs for changing chemical additions when raw water quality changes significantly. The SOPs should list the appropriate chemicals to be added and the dose according to specified raw water conditions. Jar tests or other chemical evaluations should be conducted with raw water samples representing conditions from high water quality to the worst-case scenario and should reasonably represent the treatment process.

7.4.1.2 Mixing

Adding coagulants at the proper location and providing the right amount of mixing is critical to the coagulation and flocculation processes.

- Metal salts such as alum and ferric chloride should be added at the point of highest mixing.
- Low weight polymers can be added with the metal salts or at a second stage mixing process.
- High weight polymers should be added at a point of gentle mixing.

The coagulation process occurs rapidly; therefore, it is important that the coagulant is well-dispersed and distributed across the width of the flow stream at the point of addition. Flash mixers are necessary for coagulants requiring instantaneous mixing. Systems with mechanical mixers for these types of coagulants should consider changing to a design that provides more uniform dispersion as studies have indicated that mechanical mixers experience short circuiting and frequent maintenance requirements (Kawamura 2000). Kawamura rated several flash mixer designs according to (in order of importance) effectiveness, reliability, minimal maintenance, and cost:

- 1) Diffusion mixing by pressured water jets
- 2) In-line static mixing
- 3) In-line mechanical mixing
- 4) Hydraulic mixing
- 5) Mechanical flash mixing
- 6) Diffusion by pipe grid

The mixing speed should be adjustable and changed with flow and raw water conditions as necessary. Cold water is more viscous and may require a higher mixing energy. Highly turbid or colored water may also require more mixing power to properly disperse the coagulant. For flash mixing, Kawamura (2000) recommends $G \times t$ values of 300 to 1600, where G is the mixing energy (expressed in seconds⁻¹) and t is time (seconds).

7.4.1.3 Streaming Current Detectors and Zeta Potential Monitors

The coagulation process should be monitored continuously, with real time output. Streaming current detectors (SCDs) can provide on-line coagulation control, by measuring the net surface charge of the particle and ionic species in a sample of water. Through jar testing or other coagulant studies, the charge measurement is correlated to the optimal coagulation conditions. The SCDs are typically located directly after coagulant addition to allow the operator time to adjust the dose of the coagulant before filtration. This quick response can prevent process upsets due to fluctuations in influent water quality.

Source waters high in iron or manganese concentrations and the use of treatment chemicals with iron salts or potassium permanganate can extensively increase maintenance requirements (AWWA, 2000a). Additionally, use of powdered activated carbon can increase maintenance requirements. AWWA recommends comparing the SCD measurements to jar tests and zeta potential monitoring results on a regular basis (AWWA, 2000a).

Zeta potential monitors also indicate particle surface charge and can be used in the same manner as SCDs.

7.4.2 Flocculation

The purpose of the flocculation process is to aggregate the particles into larger groups of particles or “flocs” that will settle in the subsequent sedimentation process. Through gentle and prolonged agitation, the suspended particles collide with each other and form flocs. The mixing must be thorough enough to provide opportunities for the particles to collide but also gentle enough to prevent the flocculated particles from breaking apart. It is likely, however, that some floc breakup will occur. As aggregates grow in size, they are more likely to break up due to the shearing forces in the mixing chamber. In this situation the aggregation and breakup can occur simultaneously leading to a steady-state distribution of floc sizes.

The key factors of an effective flocculation process include: adequate mixing, low floc breakup, and plug flow conditions. The following guidance can help to achieve these conditions:

- Tapered mixing is most appropriate with variable G values ranging from 70 sec^{-1} to 15 sec^{-1} .
- If flow is split between two flocculators, they should be mixing at the same speed. Coagulant dosages are most likely optimized to one speed.
- Basin inlet and outlet conditions should prevent floc breakup.
- Baffling should be adequate to provide plug flow conditions.

7.4.3 Sedimentation

The purpose of the sedimentation process is to enhance filtration by removing the flocculated particles. As with other unit processes, the sedimentation process must be optimized and provide a consistent settled water quality. The key factors of a good settling process include:

- Minimization of short circuiting.
- Sludge removal equipment should not resuspend particles or produce currents in the water.
- Surface loading rate, or overflow rate, needs to provide enough settling time. If flocculated particles are not settling it could be a function of particle density or the surface loading rate.

- Continuous or frequent turbidity monitoring of settled water.

To provide a consistent well-clarified water from the sedimentation basin, the operating parameters of the sedimentation basin may need to be adjusted with significant fluctuations in raw water quality. For example, if a runoff event causes a spike in turbidity the particles may need more time to settle, and by decreasing the flow through the basin it is possible to achieve the desired level of clarification. Table 7.4 lists sedimentation basin effluent turbidity goals for several State and industry optimization programs. Operators need knowledge and authority to modify the coagulation and flocculation processes or reduce the flow to the plant when settled water quality goals are not being met. For long-term process control, tracking seasonal raw water quality changes and their impacts on the settling process can provide valuable information for optimizing the overall sedimentation process.

Table 7.4 Effluent Turbidity Goals for the Sedimentation Process

Optimization Program	Sedimentation Basin or Clarifier Effluent Turbidity Goal
California - Cryptosporidium Action Plan	1 to 2 NTU
Texas	< 2 NTU
Partnership for Safe Water / EPA Composite Correction Program (CCP)	1 NTU for raw water conditions of ≤ 10 NTU
	2 NTU for raw water conditions of > 10 NTU

The sludge blanket level is also an important factor for optimum settling conditions. A water system should have SOPs for sludge draw-off that include routine checks of the sludge pumping lines. Sludge pumping lines can plug, causing disruption of the sludge blanket and consequently disrupting the settling process.

7.4.4 Filtration

Filtration is the last step in the particle removal process. Although filter performance is a function of the coagulation, flocculation, and sedimentation processes, proper filter operation is needed to provide the high quality finished water required for this toolbox option. The following factors should be considered when optimizing or evaluating filtration performance.

7.4.4.1 Flow Split

Systems should evaluate the flow distribution to the filters to ensure there is an even load across all filters under the range of expected operating conditions (e.g., filter out of service, backwash).

7.4.4.2 Filter Beds

The filters should be operated with a design capacity that considers at least one filter as a reserve. The reserve filter is put on-line to maintain flow stability to the filters; if this is not possible, flow to the filters should be reduced. This will allow consistent flow when one filter is backwashed or taken out of service for maintenance.

Media loss or disturbance can lead to particles passing through the filters. The filter should be inspected on a regular basis to detect changes in the media. Media should be inspected to ensure depths of media are proper, the media are evenly distributed, and the size distribution of the media are still to specifications. Media samples can be taken with a coring device or by excavation for the inspection. If media are lost or damaged, they should be replaced. Underdrains should also be examined regularly to be sure they are not damaged and causing disturbances to the media or allowing particles and media to pass out of the filter.

7.4.4.3 Backwashing

Backwashing is an integral part of the filtration process. Two important operating parameters for backwashing are the backwash flow rate and frequency of cycles. Other factors relating to backwash that affect filter effluent quality are hydraulic surges and filter start-up or “ripening”.

Flow rate

Systems should determine the appropriate flow that will clean the filter and prevent mudball formation, but will not upset the filter media and subject the underdrain to sudden momentary pressure increases. Typical flow rates are 15 to 20 gpm/ft² which result in 15 to 30 percent bed expansion.

Frequency

Although the filter effluent turbidity is the indicator for pathogen control and the determining factor for compliance, other operating parameters should be used to determine when backwash is needed. Emelko et al. (2000) performed filtration studies where pathogen breakthrough occurred towards the end of the filter cycle before an increase in turbidity was detected. Their studies emphasize the need to evaluate and optimize backwashing cycles with respect to filter effluent water quality. Most systems use filtration time, headloss, effluent turbidity, or effluent particle counts to indicate when backwashing is needed. For improved process control, it may be beneficial to use all indicators.

Systems with multiple filters also should evaluate the hydraulic surges resulting from backwashing. The timing of individual filter backwash cycles should be considered with respect to the other filters, particularly adjacent filters. Consider the following two examples:

- If a large system with 50 filters backwashed 10 filters at the same time, this would cause a 20 percent increase in flow to the other filters. In this situation, the system could backwash fewer filters at one time or reduce the flow to the filters to avoid the filter overload.
- When one filter is backwashed, a hydraulic surge can be experienced by an adjacent filter.

Improving filter effluent during start-up

It is very important for systems to conduct a full evaluation of their backwashing process and operational variations to optimize the process. At the process optimization level, systems must eliminate turbidity spikes in the filter effluent resulting from the backwashing process—it only takes a few high turbidity readings to cause non-compliance. The following operational practices may provide improved filter effluent during start-up:

- Ramping the backwash rate down in increments to allow better media gradation
- Resting a filter after backwash for several minutes or up to several hours before putting the filter in service
- Adding a polymer to the backwash water
- Slowly increasing the hydraulic load on the filter as it is brought back on line

7.4.4.4 Filter to Waste

During the beginning of a filter cycle the filter is “ripening” and the effluent turbidity is usually higher. To avoid sending this poorer quality water to the CFE stream, the filter effluent produced during the first few minutes of a filter cycle can be sent to waste (filter to waste) or recycled to the head of the plant. Some systems filter to waste or recycle until the filter effluent reaches the desired level of turbidity. Practicing filter to waste produces an overall higher quality water and may be necessary to maintain a CFE or IFE below 0.15 NTU.

7.4.4.5 Backwash Recycle

Plants that recycle the backwash water to the head of the plant should evaluate the impacts the backwash stream has on the coagulation, flocculation, and sedimentation processes. For example, the operator should know how the coagulation and flocculation processes need adjusting when there is a

change in recycle flow. Ideally, the impacts of the recycle flow on these processes should be minimized.

For systems that recycle, the Filter Backwash Rule requires spent filter backwash, thickener supernatant, or liquids from dewatering processes to be returned through all the processes of a system's existing conventional or direct filtration treatment train (40 CFR 141.76(c)). The rule allows for alternative recycle locations with State approval (40 CFR 141.76(c)).

7.4.4.6 Filter Assessments

Filter assessments can provide valuable information for optimizing the performance of a filter. The IESTWR and LT1ESWTR require systems to conduct an individual filter self-assessment if a filter exceeds specified effluent turbidity criteria. However, systems seeking *Cryptosporidium* treatment credit for lower finished water turbidity should also consider conducting filter assessments to evaluate operating parameters and optimize filter performance. Chapter 5 of the IESWTR Turbidity Guidance Manual describes how to conduct an individual filter self-assessment.

7.4.5 Hydraulic Control

Proper hydraulic control throughout the treatment process is essential. In the coagulation and sedimentation processes it is important to minimize short circuiting so the majority of the water receives the designed coagulation and sedimentation treatment. Hydraulic surges can cause greater turbulence that may break up flocculating particles and resuspend settling particles. In the subsequent filtration process, hydraulic surges can cause particle breakthrough anytime during the filtration cycle. Systems should look at historical water demand data and other conditions that adversely affect the system's ability to control filter performance (e.g., backwashing, changes in flow). With these data, they should develop operating plans to address the condition and allow control of the filter effluent quality.

7.5 Process Management Techniques

7.5.1 Standard Operating Procedures (SOPs)

Developing SOPs for all aspects of the operation and maintenance of a water system is essential for running a high quality system. SOPs provide the basis for ensuring that activities are accomplished in a consistent manner. They should be kept as simple as possible in order to ensure that each operator is consistent in carrying out the task at hand. The title of the procedure should be clear, concise, and descriptive of the equipment, process, or activity. SOPs should be developed with input from staff, thus enabling them to understand and implement procedures in compliance with applicable requirements.

7.5.2 Prevention and Response Plan for Loss of Chemical Feed

Loss of chemical feed is a common cause of increased turbidity through the treatment processes. Plants should have equipment and SOPs for preventing such occurrences or reacting to them rapidly if they do occur. The following items are necessary to prevent an upset in water quality due to a chemical feed failure.

- SOPs to verify doses with feed response time (lag time) accounted for
- Redundant feeds
- Routine maintenance of all chemical feed parts (e.g., pump, feed line)
- Inventory of spare parts available so repairs can be made quickly
- Pump or feed failure alarms
- Process monitors detecting chemical feed failure (e.g., streaming current, zeta potential, and pH monitors)

7.5.3 Adequate Chemical Storage

Sufficient chemical storage is necessary to ensure continued operation of the plant at proper dosages, including enough to run at higher dosages if an unexpected turbidity spike should occur in the raw water. Care must also be taken, however, to follow manufacturer's suggestions on the useful life of the chemical. Many coagulants will degrade over time and will not perform properly and may even cause increased turbidity if allowed to age too long. Storage tanks should also be designed so that there are no dead spaces where chemicals may accumulate with much longer residence times than the hydraulic residence time of the tank.

7.5.4 Voluntary Programs

EPA, State regulatory agencies, AWWA, and other drinking water organizations have established voluntary programs for systems to ensure the delivery of safe water to their customers. These programs often focus on optimizing the treatment process and identifying the limiting factors of performance. Consequently, they are excellent aids for systems considering this toolbox option. This section discusses two programs, the Partnership for Safe Water and the Composite Correction Program (CCP). (The CCP is also promoted as part of the Partnership for Safe Water).

7.5.4.1 Partnership for Safe Water

The Partnership for Safe Water is a voluntary cooperative effort between EPA, AWWA, and surface water systems. The goal of the program is to “provide a new measure of safety to millions of Americans by implementing prevention programs where legislation or regulation does not exist. The preventive measures are based around optimizing treatment plant performance, and thus increasing protection against microbial contamination in America’s drinking water supply.” (<http://www.awwa.org/partner/partner1.htm>).

For further information about the Partnership for Safe Water and how to join, see AWWA’s website: <http://www.awwa.org/partner/partner1.htm>

Water systems that participate in the program go through four phases:

Phase I: Commitment – operators and management indicate their willingness to complete the program through phase III.

Phase II: Data Collection and Analysis – the water system must collect one year of raw, settled, and filter effluent turbidity data and submit to AWWA for analysis.

Phase III: Self Assessment – allows the system to examine the capabilities of the existing plant’s operation and administration and identify factors that limit performance.

Phase IV: Procedures and Applications Package – systems demonstrate they addressed areas of limited performance and produce high quality water as measured by filter effluent turbidity.

Through the efforts of monitoring, data analysis, and evaluating the capabilities of unit processes, significant improvements in water quality can be achieved. In the Partnership’s 2001 Annual report, AWWA reported an increase from 20 percent to 32 percent of plants completing Phase II with finished water turbidity levels less than 0.1 NTU (based on 95th percentiles). At the beginning of Phase III, approximately 51 percent of plants reported 95th percentile turbidity less than 0.1 NTU, and after completing Phase III approximately 70 percent of plants achieved less than 0.1 NTU.

7.5.4.2 Composite Correction Program (CCP)

The CCP was developed in 1988 to optimize surface water treatment plant performance with respect to protection from microbial pathogens. The program consists of two parts, the comprehensive performance evaluation (CPE) and comprehensive technical assistance (CTA). The CPE is a thorough review and analysis of a facility’s design capabilities and associated administrative, operational, and

maintenance practices as they relate to achieving optimum performance from the facility. It can be conducted by the system or by a third party over a period of roughly 3 to 4 days. The CTA builds on the results of the CPE by addressing the combination of factors that limit a facility's performance. If conducted by a third party, it should be implemented by a third party who is in a position to pursue corrective actions in all areas, including politically sensitive, administrative, or operational limitations.

EPA published a handbook, *Optimizing Water Treatment Plant Performance Using the Composite Correction Program (1998)*, that fully describes the goals, methods, and procedures of the CCP. To obtain a copy, call the EPA Safe Drinking Water Hotline at 1-800-426-4791.

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8.0 Bag and Cartridge Filters

8.1 Introduction

Under the LT2ESWTR, bag and cartridge filters are defined as pressure driven separation processes that remove particles larger than 1 μm using an engineered porous filtration medium (generally a fabric material) through either surface or depth filtration (40 CFR 141.2). Typically, small systems use bag and cartridge filters for protozoa or other particle removal. The pore sizes in the filter bags and cartridges designed for protozoa removal are small enough to remove protozoan cysts and oocysts but generally large enough that viruses, bacteria, and fine colloidal clays could pass through.

The distinction between bag filters and cartridge filters is based on the type of filtration media used and the manner in which the devices are constructed. Bag filters are typically constructed of a non-rigid, fabric filtration media housed in a pressure vessel in which the direction of flow is from the inside of the bag to the outside. Cartridge filters are typically constructed as rigid or semi-rigid, self-supporting filter elements housed in pressure vessels in which flow is from the outside of the cartridge to the inside. A pressure vessel may contain either single or multiple filters in a series or in parallel.

As the water flows through a bag or cartridge filter, particles collect on the filter and the difference in pressure from the inlet to the outlet, termed “pressure drop,” increases. Once a “terminal pressure drop” is reached, the bag or cartridge filter must be replaced. Bag and cartridge filters are disposable and designed to be easily replaced; however, a few cartridge filter devices are reportedly designed to be cleaned and operated through multiple filtration cycles.

This chapter provides background information on the treatment performance, design, and operation of bag and cartridge filters, with emphasis on those issues that a system should consider for integrating bag or cartridge filters into its treatment process to comply with the LT2ESWTR. This chapter is organized as follows:

- 8.2 LT2ESWTR Compliance Requirements - describes criteria and reporting requirements that systems must meet to receive *Cryptosporidium* treatment credit.
- 8.3 Toolbox Selection Considerations - describes the advantages and disadvantages of integrating a bag and cartridge filtration process for compliance with the LT2ESWTR.
- 8.4 Challenge Testing - describes the challenge testing that a bag or cartridge filter must pass to be awarded *Cryptosporidium* treatment credit for the LT2ESWTR.
- 8.5 Design Considerations - discusses influent water quality, size of filter system and redundancy, layout features, filter cycling, pressure monitoring, valves and appurtenances, air entrapment, and NSF certification.

- 8.6 **Operational Issues** - discusses pressure drop across the filter, and monitoring to assess performance and indicate possible process upsets with the bag or cartridge filter or other upstream processes.

8.2 LT2ESWTR Compliance Requirements

8.2.1 Credits

Bag and cartridge filtration processes that meet the EPA definition and demonstrate *Cryptosporidium* removal through challenge testing may receive the following *Cryptosporidium* removal credit for the LT2ESWTR (40 CFR 141.728(a)):

- 1 log removal for bag filtration showing a minimum of 2 log removal in challenge testing
- 2 log removal for cartridge filtration showing a minimum of 3 log removal in challenge testing

A 1 log factor of safety is applied to the allowable removal credit over that demonstrated by challenge testing because bag and cartridge filters cannot have their integrity directly tested; hence, there are no means of verifying their removal efficiency during routine use.

Recently, some cartridge filtration devices have been developed for drinking water treatment using membrane media, which can be direct integrity tested. These membrane cartridge filters (MCFs) could be considered a membrane filtration process for the purpose of compliance with the LT2ESWTR treatment requirements for *Cryptosporidium* (i.e., the MCF process would be eligible for the same credit, and subject to the same requirements, as a membrane filtration process). A direct integrity test is a physical test applied to a membrane unit to identify and isolate integrity breaches (i.e., one or more leaks that could result in contamination of the filtrate). Manufacturers can provide information on direct integrity testing and whether it is feasible with their products. Refer to the *EPA Membrane Filtration Guidance Manual* for direct integrity testing and other membrane filtration requirements.

States may choose to award removal credits in excess of 1 and 2 log for bag and cartridge filtration, respectively, if challenge testing demonstrates that the process can reliably achieve a greater removal efficiency.

8.2.2 Reporting Requirements

All reporting requirements for the Surface Water Treatment Rule (SWTR), Interim

Enhanced Surface Water Treatment Rule (IESWTR), and Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR) are still applicable; the LT2ESWTR does not modify or replace any previous rule requirements. The location of filter effluent turbidity monitoring for compliance with the IESWTR and LT1ESWTR does not change with the installation of a bag or cartridge filter as a secondary filtration process. That is, a system would still monitor filter effluent turbidity after the primary filters for compliance with the IESWTR and LT1ESWTR.

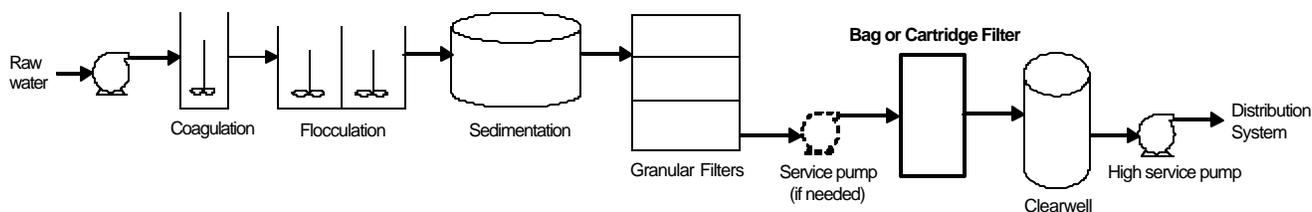
The LT2ESWTR requires an initial report be submitted by [72 months after rule promulgation] for large systems and [102 months after rule promulgation] for small systems that demonstrates the following (40 CFR 141.730):

- Process meets the definition of a bag or cartridge filter
- Removal efficiency from challenge testing (described in section 8.4) that must show at least 2 log removal for bag filters and 3 log removal for cartridge filters

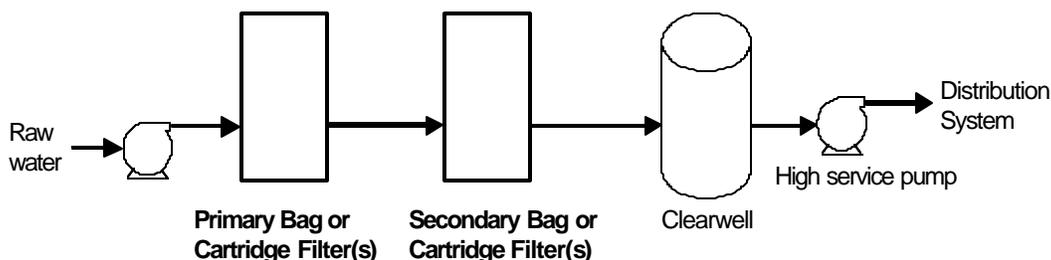
For routine compliance reporting, the rule requires verification that all flow was treated by the bag or cartridge filter (40 CFR 141.730). One possible approach States may elect to use for flow verification is to have operators certify each month that all flow was treated by the filter. States may require additional reporting at their discretion. Section 8.6 provides recommendations for filter effluent and process monitoring.

8.2.3 Integration Into a Treatment Process Train

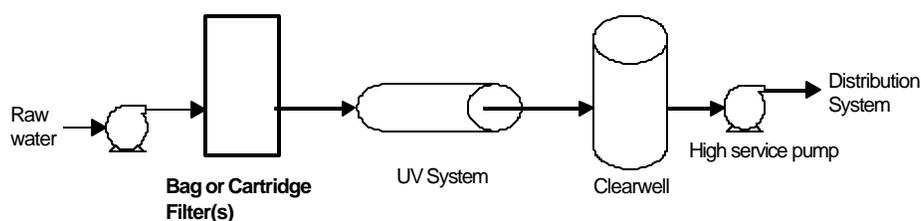
To achieve compliance with the IESWTR and LT1ESWTR, all plants (except those meeting the filter avoidance criteria in 40 CFR 141.71) must have a filtration process approved by the State. Approved processes receive 2 log *Cryptosporidium* removal credit under the IESWTR and LT1ESWTR. For compliance with additional treatment requirements for the LT2ESWTR, bag and cartridge filters should be added as an additional filtration process following the existing primary filtration (see Figures 8.1 and 8.2). The bag and cartridge filters provide additional removal of the smaller contaminants and any contaminants that break through the granular media filters during the end of a run cycle or process upsets.

Figure 8.1 Schematic of Treatment Process with Bag/Cartridge Filters

For those systems using a bag or cartridge filter process to meet LT1ESWTR requirements, thus serving as the primary filtration process, it may be possible to configure the bag or cartridge filters in a series (see Figure 8.2).

Figure 8.2 Bag/Cartridge Filters in Series

Another possible configuration is a bag or cartridge filter followed by a UV system (see Figure 8.3). This configuration would allow removal of particles and microbial pathogens as well as inactivation of *Cryptosporidium*, *Giardia*, and viruses. In this case, the bag or cartridge filter would serve as the primary filter and thus, be subject to SWTR, IESWTR, and LT1ESWTR requirements, while the UV system would be subject to the LT2ESWTR requirements. Refer to EPA's *UV Disinfection Guidance Manual* for information regarding UV systems and associated requirements with LT2ESWTR.

Figure 8.3 Bag/Cartridge Filter with UV System

Other factors that should be considered when developing a treatment process scheme include available space, hydraulic profile, and point of disinfection. Space requirements are small for bag and cartridge filter systems, but extra space for maintenance activities should be accounted for in the planning process. Because a significant head loss is associated with an additional filtration process, a utility should consider its hydraulic profile when integrating new filters into an existing process sequence. Although the addition of a new bag filtration process does not necessarily require that the point of primary disinfection be changed, some bag filtration applications chlorinate prior to the bag filtration process to minimize biofilm growth on the bags. However, if considering a process train with a bag or cartridge filter as the primary filter, as in Figure 8.3, chlorinating prior to filtration will likely cause higher disinfection byproduct formation compared to post-filter chlorination since the filtration process will remove some organic material.

8.3 Toolbox Selection Considerations

This section describes the advantages and disadvantages of integrating a bag and cartridge filtration process for compliance with the LT2ESWTR.

8.3.1 Advantages

The advantages of bag and cartridge filtration processes include low maintenance requirements, relatively low capital cost, minimal operator skill and attention required, and low space requirements. The only routine maintenance required is filter replacement when a defined terminal pressure drop or other operating parameter, such as filter age or volume treated, is reached. The operation of these systems is straightforward and requires little technical skill. In addition, the filter materials are relatively inexpensive and the housing system is not complex, resulting in relatively low capital costs.

8.3.2 Disadvantages

A disadvantage of bag and cartridge filtration processes is most filters must be replaced instead of regenerated. For larger flows, or water with higher particle loads, frequent filter replacement increases operation and maintenance costs. Additional pumps may be required to provide needed pressure. Also, redundancy should be built into the process design, increasing costs.

8.4 Challenge Testing

Manufacturers commonly rate fabric filters by pore size or pore distribution. However, there is no industry standard for measuring or reporting these characteristics. This lack of standardization causes problems for establishing design criteria to ensure that a given bag or cartridge filter will effectively remove a given percentage of *Cryptosporidium*. Furthermore, an oocyst has different structural characteristics than the markers used to determine pore size; thus, the rate of rejection may differ for an oocyst versus the test markers used to determine pore size or molecular weight cutoff. To compensate for these factors of uncertainty for *Cryptosporidium* removal, the LT2ESWTR requires bag or cartridge filters to be challenge tested—a process in which a known quantity of *Cryptosporidium* oocysts (or an acceptable surrogate) is added to the filter influent and the effluent concentration is measured to determine the removal capabilities of the filter (40 CFR 141.728(a)). This testing is product-specific, not site-specific, meaning it does not have to be tested at every water system seeking removal credit. Instead, a manufacturer (or independent third party) would challenge test each of its products in order to obtain a 1 or 2 log *Cryptosporidium* removal rating.

For compliance with the LT2ESWTR, EPA defined a set of test conditions that must be met for an acceptable challenge test. These conditions provide only a framework for the challenge test and States may develop additional testing requirements. The EPA *Membrane Filtration Guidance Manual* contains detailed guidance on developing challenge test protocol and conducting the test for membrane processes that relate to these requirements. Additionally, NSF International, in cooperation with EPA, developed the *Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants* with a chapter for testing bag and cartridge filters. Although the protocol was developed for compliance with the SWTR, some¹ testing principles still apply.

Section 8.4.1 describes the test conditions required by the LT2ESWTR (40 CFR 141, Subpart W, Appendix B). Section 8.4.2 shows how to calculate the log removal value for challenge testing

¹ Specific sections of the EPA/NSF ETV Protocol that provide guidance for developing and conducting a challenge test for LT2ESWTR include: section 10.4, Pre-Filter Water Quality Analysis; section 11.0, Operating Conditions; section 12.3, Workplan; section 13.0, Data Management; and section 14.0, QA/QC.

results. Section 8.4.3 discusses modifications to the filter unit (e.g., change in filter media) occurring after challenge testing that may require additional challenge testing.

8.4.1 Testing Conditions (141, Subpart W, Appendix B)

8.4.1.1 Full Scale Filter Element

Challenge testing must be conducted on a full-scale filter element identical in material and construction to the filter elements proposed for use in full-scale treatment facilities. For this challenge testing, a filter element consists of the filter media, filter housing, and inlet and outlet piping.

8.4.1.2 Challenge Particulate

Challenge testing must be conducted using *Cryptosporidium* oocysts or a surrogate which is removed no more efficiently than *Cryptosporidium* oocysts. The organism or surrogate used during challenge testing is referred to as the “challenge particulate.” The concentration of the challenge particulate must be determined using a method capable of discreetly quantifying the specific organism or surrogate used in the test, and gross measurements such as turbidity cannot be used. Key physical characteristics to be considered for identifying an acceptable surrogate include size, shape, surface charge, and mono-dispersion (i.e., particles remain discrete in solution and do not aggregate).

Chapter 3 of EPA’s *Membrane Filtration Guidance Manual* describes the characteristics of acceptable surrogates and lists potential and inert surrogates for *Cryptosporidium*. Examples of possible microbial surrogates are *P. dimunita* and *Serratia marcessans*.

8.4.1.3 Feed Concentration

In order to demonstrate a removal efficiency of at least 2 or 3 log for bag or cartridge filters, respectively, it may be necessary to seed the challenge particulate into the test solution. A criticism of this approach is that the seeded levels are orders of magnitude higher than those encountered in natural waters, which could lead to artificially high estimates of removal efficiency. To address this issue, EPA set a limit on the maximum feed concentration applied to a filter during the challenge study. The limit is based on the detection limit of the challenge particulate:

Cartridge filters: Maximum Feed Concentration = $3.16 \times 10^4 \times$ Filtrate Detection Limit

Bag filters: Maximum Feed Concentration = $3.16 \times 10^3 \times$ Filtrate Detection Limit

These concentrations allow the demonstration of up to 3.5 log removal for bag filters and 4.5 log removal for cartridge filters during challenge testing, if the challenge particulate is removed to the detection limit.

8.4.1.4 Time Periods of Challenge Testing

The challenge test must run until “terminal pressure drop” is reached. Terminal pressure drop is a parameter specified by the manufacturer which establishes the end of the useful life of the filter. However, continuous challenge particulate feed is not required (i.e., intermittent seeding is permitted). At a minimum, removal efficiency must be determined during three periods over the filtration cycle:

- 1) Within 2 hours of start-up after a new bag or cartridge filter has been installed.
- 2) When the pressure drop is between 45 and 55 percent of the terminal pressure drop.
- 3) At the end of the run after the pressure drop has reached 100 percent of the terminal pressure drop.

The rule does not specify the number of samples that must be collected during each of the three periods. Because the effluent concentration is often very low and near the detection limit, it may be beneficial to collect more effluent than influent samples to obtain a more accurate removal efficiency. If one sample has an uncharacteristically high concentration this can result in a low log removal value (LRV) that is not necessarily representative of the filter’s removal efficiency.

8.4.1.5 Water Quality of Challenge Test Solution

Water quality can have a significant impact on the removal of particulate contaminants, such as *Cryptosporidium*. In general, bag and cartridge filters in water treatment do not experience influent turbidity concentrations much greater than 10 NTU; and for the application of the LT2ESWTR, will receive filtered water and thus, very low turbidity.

A clean-water challenge test will generally provide the most conservative estimate of removal efficiency. However, since the challenge test must run until terminal head loss is reached, the challenge test solution will need to contain some solids to cause the head loss build-up across the filter, but not an excessive amount that will cause a rapid build-up. Particulate foulants that may be appropriate to add to the test solution include clay particles (such as bentonite or kaolin) or carbon powder, as long as they are not excessively fine-sized.

The following are recommended for the challenge test solution:

- High quality water with a low to moderate concentration of suspended solids should be used as the challenge solution. Suspended solids concentration should be high enough to achieve a reasonable rate of headloss buildup, but not so high that the headloss builds up too rapidly to conduct the challenges at the various headloss levels.
- No oxidants, disinfectants, or other pretreatment chemicals should be added to the test solution.
- Characterized with respect to basic water quality parameters, such as pH, turbidity, temperature, and total dissolved solids.

For the initial sampling conducted at zero percent headloss (see section 8.4.1.8), no particulate foulant needs to be added to the test solution. This can be accomplished if the foulant is injected into the feed stream, rather than fed in batch. In this case the foulant feed pump would not be turned on until the zero percent challenge is completed. If the particulate foulant is added in batch, then the zero percent headloss challenge must be completed before five percent of the terminal headloss is reached.

8.4.1.6 Maximum Design Flow Rate

The challenge test must be conducted at the maximum design flow rate specified by the manufacturer.

8.4.1.7 Challenge Particulate Seeding Method

There are two basic approaches to seeding: batch seeding and in-line injection. In batch seeding, all of the challenge particulates are introduced into the entire volume of test solution and mixed to uniformity. In-line injection allows for the continuous or intermittent introduction of challenge particulates into the feed stream entering the bag or cartridge system. While both methods are acceptable, intermittent, in-line injection may be the most practical seeding method for the testing.

Batch seeding requires the entire test solution to be contained in a reservoir and for the reservoir to be well mixed to ensure a uniform concentration of the seeded particles. Generally, batch seeding is used for small scale systems that only require relatively small amounts of feed solution for testing.

While, in-line injection of the challenge particle can be either continuous or intermittent, the intermittent feed may be more practical to conduct the challenge test at the required periods (i.e., a

minimum of beginning, middle, and end-of-run; see section 8.4.1.4). It is vital that equilibrium is achieved during each seeding event prior to the collection of feed and filtrate samples.

In-line injection delivers the challenge particles from a concentrated stock solution with a known feed concentration (C_{stock}). The concentration of the stock solution should be 50 to 200 times the desired concentration in the test feed solution (C_{feed}). The stock solution delivery rate (SSDR) for in-line injection is calculated using the equation below:

$$\text{SSDR} = (C_{\text{feed}} \times Q_{\text{feed}}) / C_{\text{stock}} \quad \text{Equation 8-1}$$

Where:

SSDR	= stock solution deliver rate (gpm)
C_{feed}	= feed solution concentration (# or mass / volume)
Q_{feed}	= feed flow (gpm)
C_{stock}	= stock solution concentration (# or mass / volume)

The stock solution should be continuously mixed to ensure a uniform concentration of particles are injected into the feed stream.

In-line injection requires additional equipment, such as chemical feed pumps, injection ports and in-line mixers. A more detailed description of in-line injection is available in the *Membrane Filtration Guidance Manual* (USEPA, 2003).

8.4.1.8 Challenge Test Solution Volume

The total volume of test solution required for the challenge should be the same for the different challenge particle seeding methods. However, the seeded test solution volume can differ for the different methods.

In general, the volume of the test solution depends on filtrate flow rate, test duration, and hold-up volume of the test system and can be calculated by the following equation.

$$V_{\text{test}} = (Q_f \times T + V_{\text{sys}}) \times \text{SF} \quad \text{Equation 8-2}$$

Where:

V_{test}	= Volume of test solution (gallons)
Q_f	= Filtrate flow rate (gallons per minute)
T	= Duration of test (minutes)
V_{sys}	= Volume of solution contained within the filter unit(gallons)
SF	= Safety factor (dimensionless)

To calculate the total volume of test solution, the T value in the above equation is the time between the initiation of flow to the filter unit to the time the last sample is drawn when terminal headloss is reached. For batch seeding and continuous in-line injection tests, the seeded test solution volume (V_{seeded}) is the same as the total test solution volume.

For intermittent, in-line injection, the seeded test solution volume can be considerably less than that required for batch seeding. To calculate this smaller volume, the equation above can be modified as follows:

$$V_{\text{seeded}} = (Q_f \times T_{\text{seed}} + V_{\text{sys}} + V_{\text{eq}}) \times \text{SF} \quad \text{Equation 8-3}$$

Where:

$$\begin{aligned} V_{\text{seeded}} &= \text{seeded test solution volume (gallons)} \\ V_{\text{eq}} &= \text{volume required to reach feed equilibrium (gallons)} \\ T_{\text{seed}} &= \text{Duration of sampling (minutes)} \end{aligned}$$

The equilibrium volume (V_{eq}) is the quantity of seeded test solution needed to pass through the filter to reach a stable feed concentration of the challenge particle. In general, filtrate sampling cannot begin until this volume has passed through the system. A common assumption is that a minimum of three to five system volumes are needed to reach equilibrium (i.e., $V_{\text{eq}} \geq 3V_{\text{sys}}$). The duration of the test, T, does not include time needed to reach equilibrium, as this is accounted for by V_{eq} . Thus, T represents the time necessary to conduct the actual sampling as discussed in section 8.4.1.9). Section 3.10.5 of the *Membrane Filtration Guidance Manual* (USEPA, 2003) contains a detailed example of challenge test solution design.

For in-line injection of the challenge particles the volume of stock solution needed can be calculated from the seeded test volume as follows:

$$V_{\text{stock}} = (V_{\text{seeded}} \times C_{\text{feed}}) / (C_{\text{stock}}) \quad \text{Equation 8-4}$$

Where:

$$\begin{aligned} V_{\text{stock}} &= \text{volume of stock solution (gallons)} \\ V_{\text{seeded}} &= \text{seeded test solution volume (gallons)} \\ C_{\text{feed}} &= \text{feed solution concentration (\# or mass / volume)} \\ C_{\text{stock}} &= \text{stock solution concentration (\# or mass / volume)} \end{aligned}$$

8.4.1.9 Sampling

An effective sampling program depends on a detailed sampling plan and the use of appropriate sampling methods, locations, and QA/QC measures.

Samples can be collected using either grab or composite sampling methods. Grab samples consist of pre-determined amounts of water taken from the feed or filtrate streams, while composite samples are of the entire process stream. It is likely that grab sampling methods will be used in the challenge test. Good sampling practices include flushing samples taps, using clean sample containers and preventing cross contamination of samples. QA/QC measures include clearly identifying samples, collecting duplicates and using blanks. The time of filtrate sampling should be based on the initiation of seeding for a given sampling period and flow rate. The influent should be sampled just prior to entering the filter (but at least 10 pipe diameters downstream of the particle injection point and in-line mixers). Sampling of the filtrate should occur immediately following the filter, but after any filtrate side instrumentation that may be affected by the sampling.

Sample port design is an important consideration and should ensure that a representative sample is obtained. Poorly designed ports contain large volumes where stagnation may occur (e.g., large valves and long sample tubes) and pull the sample from the edge of the pipe. A well designed port has a sample quill that extends into the center of the pipe to draw a more representative sample.

Chapter 3 of the *Membrane Filtration Guidance Manual* (USEPA, 2003) contains additional information on developing sampling plans and provides schematics of typical sampling apparatuses.

8.4.2 Calculation of Log Removal

To determine the maximum feed concentration, use Equation 8-5. To determine the log removal efficiency of the filter process tested, calculate the log removal using Equation 8-6.

$$\text{Maximum Feed Concentration} = 3.16 \times 10^6 \times (\text{Filtrate Detection Limit}) \quad \text{Equation 8-5}$$

$$\text{LRV} = \text{Log}_{10}(\text{Feed Concentration}) - \text{Log}_{10}(\text{Filtrate Concentration}) \quad \text{Equation 8-6}$$

The feed and filtrate concentrations must be expressed in the same units (number of challenge particulate per unit volume). If the challenge particulate is not detected in the filtrate, then the filtrate concentration is set equal to the detection limit.

Example 1 - Determining maximum allowable filtrate concentration

If the detection limit of the surrogate test is 2 units/L then the maximum feed concentration is $3.16 \times 10^6 \times (2) = 6.32 \times 10^6$

Example 2 - Calculating the LRV

Feed Concentration	20,000 units/L
Filtrate Concentration	3 units/L

$$\text{LRV} = \text{Log}(20,000) - \text{Log}(3)$$

$$\text{LRV} = 4.30 - 0.48 = 3.82$$

The LT2ESWTR does not specify how the feed and effluent concentration must be determined. One possible approach is to use the average of all the feed samples and average of all the filtrate samples. A more conservative approach would be to use the lowest feed concentration and highest filtrate concentration from each filter run.

A challenge test will likely evaluate multiple filters. An LRV must be calculated for each filter tested. The final log removal efficiency assigned to the filter process tested depends on the number of filters tested:

- If fewer than 20 filters were tested during a challenge study, then the lowest LRV observed would be the removal efficiency assigned to the process.
- If 20 filters were tested during challenge testing, then the removal efficiency assigned for the process is the 10th percentile of the LRVs observed during the challenge study. (The percentile is defined by $[i/(n+1)]$ where i is the rank of n individual data points ordered lowest to highest. If necessary the system may calculate the 10th percentile using linear interpolation.)

8.4.3 Modifications to Filtration Unit after Challenge Test

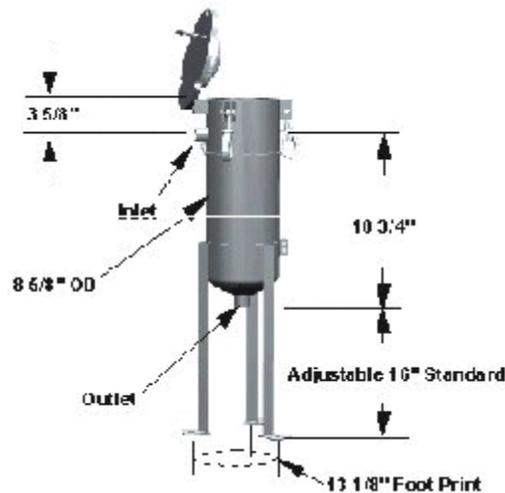
If any significant modifications to the filter unit are made after challenge testing, additional challenge testing is required to demonstrate removal efficiency of the modified unit. Significant modifications specified by the rule are, but not limited to:

- Changes to the filtration media (e.g., different fabric, change in the filter manufacturing process)
- Changes to the configuration of the filtration media
- Modifications to the sealing system

8.5 Design Considerations

Bag and cartridge filter systems may contain anywhere from one to over twenty filter units. There is no maximum number of filters a system can include; however, membrane or other filtration processes become more practical for larger flows since bag and cartridge filters are generally replaced instead of backwashed or regenerated. A single filter unit is comprised of the filter media (bag or cartridge), housing, and associated piping and valves. Figure 8.4 shows a typical single filter vessel (housing).

Figure 8.4 Single Filter Vessel



Source: U.F. Strainrite

Systems with multiple filters may be designed as a manifold with connective piping between the individual filters in separate housing or alternatively as multiple filters in a single housing. Figures 8.5 and 8.6 show the manifold design and multiple filter vessel design, respectively.

Figure 8.5 Manifold Bag Filter Design

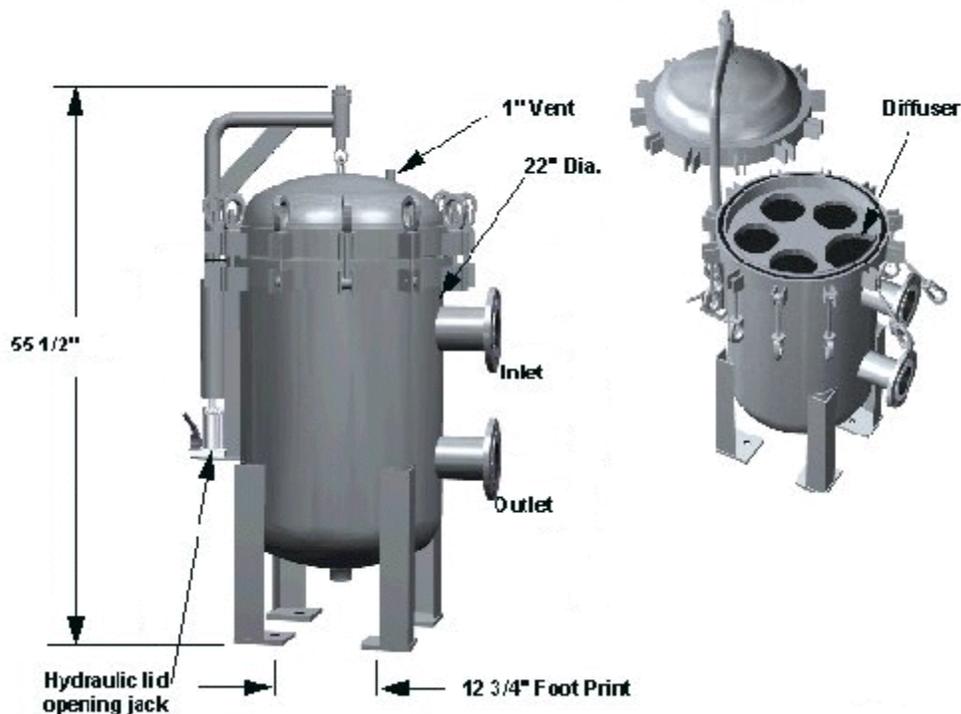


Source: U.F. Strainrite

The designs of bag and cartridge filters are not complex, however, there are a couple of key issues that should be taken into consideration. First, the filter units must be designed integrally with their respective housing systems. Poor fittings can cause leaks and premature failure. Manufacturers can provide individual filter units that can be retrofitted into the existing process or complete filter houses that are skid mounted. *It is important to adhere to the manufacturer's instructions on filter installation.*

Second, the overall water treatment process design should minimize sudden changes in pressures applied to the bag or cartridge filters. Each time the flow to the filter is interrupted and then restarted, a sudden increase in pressure can occur across the filter unit unless steps are taken to allow for gradual pressure ramp-up. The particle load in the filter effluent often increases when the filter cycle begins. A study by McMeen (2001) reported that the increase in particle load could be occurring due to the seal at the top of the filter failing when the pressure suddenly increases. Bag filters are especially susceptible to cycling because these pressure fluctuations also increase wear on the fabric and seams, causing premature failure. Section 8.5.4 provides recommendations for reducing filter cycling.

Figure 8.6 Multiple Filter Vessel



8.5.1 Water Quality

As previously described, systems seeking compliance with the LT2ESWTR will most likely integrate a bag or cartridge filter process after the primary filtration process. As a result, influent water quality, with respect to high particulate levels, should not be an issue. However, for systems with existing processes that use coagulants, the presence of residual coagulant in the primary filter effluent may clog the pores of a bag or cartridge filter. Although this will not impair removal efficiency for *Cryptosporidium*, it will shorten the time until the terminal pressure drop is reached, thus reducing filter life.

Another water quality issue is the potential for biofilm growth on the bag or cartridge filter media. Systems can add a disinfectant prior to the bag or cartridge filters to prevent biofilm growth. (The filters must be compatible with the disinfectant.)

8.5.2 Size of Filter System and Redundancy

Systems should be adequately designed to handle maximum day or maximum instantaneous flow, depending on the existing treatment process design. Prolonged operation at maximum flow velocity wears the filter media at a higher rate than operating at lower flow velocities. The total volume throughput is greater when operating at a flow velocity lower than maximum flow velocity rated for the filter.

A minimum of two bag or cartridge filter housings should be provided to ensure continuous water treatment in the event of failure in the filter operation. For water systems that do not require continuous operation, a State may approve a single filter housing operation. Redundancy in pumps is also recommended to ensure continuous operation.

8.5.3 Design Layout

Design layout features that should be considered for most designs are as follows:

- Piping should be designed to allow isolation of the individual filter units or vessels for maintenance and filter replacement
- Common inlet and outlet headers for the filter units
- Sufficient available head to meet the terminal pressure drop and system demand

8.5.4 Filter Cycling

Filter cycling refers to the starting and stopping of the pump or filter operation. This can be problematic with bag filter processes (cartridge filters are not known to have this problem) in which water is pumped directly from the source to the filter, and then out to the distribution system. In these situations, the filters operate on demand, similar to wells for small systems, and the sudden increase in pressure across the filter causes premature wear and filter failure. For LT2ESWTR compliance, systems with bag filters in a series or followed by UV disinfection should consider the following recommendations for controlling the flow into the filter process to minimize filter cycling.

- Lengthen the filter runs by reducing the flow as much as possible through the filter.
- Install or divert the flow to a storage facility (e.g., pressure tank, clearwell) after the bag filtration process. The stored water can supply the frequent surges in demand and thus reduce the bag or cartridge filter cycling.

During filter start-up and other hydraulic surges, bag and cartridge filters often experience an increase in filter effluent turbidity. Systems should consider the following options to improve filtered water quality:

- Design for filter to waste capability. EPA strongly recommends **filtering to waste for the first five minutes** of the filter cycle.
- Install a slow opening and closing valve ahead of the filter to reduce flow surges.

8.5.5 Pressure Monitoring, Valves, and Appurtenances

As previously mentioned, once the terminal pressure drop has been reached, the filter should be replaced. At a minimum, pressure gauges should be located before and after the bag or cartridge filter system and should be monitored at least daily. A valve or flow restricter should be installed on the inlet header pipe of the filters to maintain flows below the maximum operating flow for the filters.

8.5.6 Air Entrapment

An automatic air release valve should be installed on the top of the filter housing to release any air trapped in the filter. These valves should be checked routinely and properly maintained.

8.5.8 NSF Certification

All components used in the drinking water treatment process should be evaluated for contaminant leaching and certified under ANSI/NSF Standard 61.

8.6 Operational Issues

8.6.1 Pressure Drop (Inlet/Outlet Pressures)

The pressure drop across the filter directly relates to the amount of particle build-up on the filter material and to the time when the filter should be replaced. Typical pressure drops across a clean filter are 1 to 2 psig (pounds per square inch-gauge) and can increase to a differential of 20 to 30 psig when the terminal pressure drop is achieved. The pressure differential does not increase linearly with run time; the differential pressure increases at a faster rate with the duration of the run or as more material accumulates on the filter. The time between filter replacement is primarily dependent on flow rate, but also on influent water quality and filter material (i.e., size of pores).

The differential pressure between the inlet and outlet header should be monitored to determine when the filter needs replacement. An alarm could also be linked to the pressure gauge to ensure the operator is alerted.

8.6.2 Monitoring

In addition to monitoring the pressure drop across the filter, the influent and effluent turbidity or particle count should be monitored to assess performance and indicate possible process upsets with the bag or cartridge filter or other upstream processes. The recommended monitoring frequency depends on the influent water quality and its variability. At a minimum, the pressure differential and effluent turbidity should be checked daily. During the initial start-up phase of a newly integrated bag or cartridge filtration system, monitoring should be more frequent and then can be reduced once the operator becomes familiar with the system. If continuous monitoring of turbidity and/or pressure differential is employed, the output from the sensors should be sent to an alarm to warn operators of sudden changes in operation, or if the filter element needs replacing.

EPA recognizes turbidity has limitations as an indicator of filter failure or pathogen breakthrough. However, in the absence of a better indicator, monitoring both influent and effluent turbidity over a full run (i.e., from start to end of the filter life) can provide a performance baseline. The baseline can then be used to indicate process upsets. This method may not be applicable to all systems;

since the bag or cartridge filter influent will be filtered water, the difference between influent and effluent turbidity may be too low to provide meaningful data.

Particle counters can be another valuable monitoring tool. If available, periodic checks of influent and effluent particle counts are also recommended to ensure the filter is removing particles in the appropriate size range (i.e., 4-6 microns).

References

McMeen (2001). *Alternate Filtration: Placing New Technology in an Old Regulatory Box*. American Water Works Association, Membrane Conference Proceedings.

NSF International. (2000). *Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants*. 40CFR35.6450.

USEPA (2002). *Draft Membrane Filtration Guidance Manual*, April 2002 draft.

9.0 Second Stage Filtration

9.1 Introduction

The LT2ESWTR 40 CFR 141.728(c) describes second stage filtration as the use of a rapid sand, dual media, granular activated carbon (GAC), or other fine grain media unit process applied in a separate stage following rapid sand or dual media filtration. Applying an additional layer of media, such as a GAC cap, on an existing single stage filtration unit does not qualify for this credit.

This chapter is organized as follows:

- 9.2 LT2ESWTR Compliance Requirements - discusses criteria and reporting requirements that systems must meet to receive *Cryptosporidium* removal.
- 9.3 Toolbox Selection Considerations - discusses issues specific to second stage filtration that water systems should consider when selecting toolbox options.
- 9.4 Design and Operational Considerations - discusses hydraulic issues, backwashing, and turbidity monitoring for systems that integrate a second stage filtration in their treatment train.

9.2 LT2ESWTR Compliance Requirements

9.2.1 Credits

Under the LT2ESWTR, a system that employs a second, separate filtration stage meeting the following criteria may receive 0.5 log credit for *Cryptosporidium* removal (40 CFR 141.728(c)).

- The first stage of filtration is preceded by a coagulation step
- The second stage of filtration is comprised of rapid sand, dual media, GAC, or other fine grain media
- Both filtration stages treat 100 percent of plant flow

Under the LT2ESWTR, a system integrating a slow sand filtration process for the second stage of filtration meeting the following criteria can receive 2.5 log credit for *Cryptosporidium* removal (40 CFR 141.728(d)).

- No disinfectant residual is present in the influent to the slow sand filtration process
- Both filtration stages treat 100 percent of plant flow

9.2.2 Reporting Requirements

To receive *Cryptosporidium* removal credit for compliance with the LT2ESWTR, systems must report the following monthly (40 CFR 141.730):

- Verification that 100 percent of finished water was treated by two stages of filtration. Actual data or information required to report is determined by the State. EPA recommends plant piping schematics be initially reported followed by monthly operator certification.

Reporting for LT2ESWTR does not take the place of the IESWTR and LT1ESWTR reporting requirements. Specifically, the turbidity of the combined and individual filter effluent from the *first* filtration stage must be reported as required by the IESWTR and LT1ESWTR (40 CFR 141.74, 40 CFR 141.174(a), 40 CFR 141.551, and 40 CFR 141.560).

9.3 Toolbox Selection Considerations

Plants already employing a second unit process that meets the requirements for this toolbox option (e.g., GAC columns to meet dissolved organic or taste and odor treatment goals) are in the ideal position to seek credit. Other plants that have enough excess filtration capacity or unused filter beds (e.g., built in anticipation of unrealized plant expansions), may be able to convert piping to enable these filters to operate in series for relatively low cost. However, many plants will find that integrating second stage filtration into an existing treatment train poses significant additional space, capital, and hydraulic requirements. These systems may want to consider this option if the additional treatment provides other benefits. For example, systems that use chloramination and/or ozone could run the second stage under biological filtration conditions to reduce assimilable organic carbon (AOC), which promotes biofilm growth and nitrification (for chloraminating systems) in the distribution system.

Additionally, plants experiencing taste and odor problems or dissolved organic contaminants in their raw water might consider installing GAC columns to alleviate these problems and also receive the *Cryptosporidium* removal credit.

Slow sand filtration plants who wish to consider this toolbox option should either have sufficient excess filtration capacity to allow filters to operate in series (with possible piping modifications) or have sufficient land area to build additional filters.

9.3.1 Advantages

The advantages of a second stage filtration process are the same for both rapid and slow sand plants and include operator familiarity with the process, ease of operation, and potential to reduce disinfection byproducts. For plants with existing processes and infrastructure meeting the two-stage requirements, implementation costs are likely to be relatively low.

9.3.2 Disadvantages

The disadvantages associated with second stage filtration apply primarily to those plants that do not have existing processes in place or cannot easily convert built-in infrastructure. In addition to the capital cost for new filters, these plants may need the following improvements to integrate a second stage of filtration:

- Space if there is currently no room for expansion in the existing plant grounds
- Additional pumping to compensate for head loss associated with an additional filtration process
- Increased backwash supply and treatment

For those plants that have existing infrastructure available for a second stage of filtration, they still may have to account for an increased volume of backwash and loss of head due to the second stage.

Systems with rapid sand filtration plants that are considering integrating slow sand filtration into their treatment process should be aware of the following differences in operation and performance of slow sand plants compared to rapid sand plants:

- More space required for slow sand plants
- Decreased filtering performance with cold temperatures
- Maintenance of filters requires draining and scraping a thin layer off the top of the filter

9.4 Design and Operational Considerations

The design of the second stage is site-specific and depends on existing infrastructure (e.g., some systems may have enough filtration capacity to operate filters in series) and space and hydraulic requirements. EPA does not specify or restrict certain configurations, beyond the requirement that all flow must be treated by both stages. Systems that have existing filters not in use or not used to capacity may reconfigure the piping to operate in series. Media sizing for the second stage is also not specified; however, typical design standards for regular or deep bed filters should be followed. If the filter effluent from the first stage is not combined prior to second stage, the turbidity monitoring for IESWTR and LT1ESWTR may have to be conducted on individual filters. For these cases, systems need to consult with the State to develop a new IESWTR or LT1ESWTR filter effluent monitoring plan.

9.4.1 Hydraulic Requirements

Additional pumps may be needed to provide the necessary head between the first and second stages of filtration. The number of pumps and total number of filters should allow for redundancy, to ensure that sufficient treatment capacity is in place to treat all the plant flow in the event of equipment breakdown or maintenance. However, the filter loading rate to the second stage does not necessarily need to be the same as for the first stage. The water influent to the second stage should be significantly cleaner, and may enable higher loadings. Final design loading rates should be determined in consultation with the State.

If the filter effluent from the first stage filters is not combined and sent to the second stage filters via a distribution box or other flow equalization device, plant operation may be more complex. For example, if the effluent from one first stage filter is sent to just one second stage filter, then as the flow from first filter decreases (or headloss through it increases), flow through the second filter will also decrease, unless automatic effluent control valves are installed on the second stage filter. Also, in this case, whenever the first stage filter is backwashed, the second stage filter will also be out of service.

9.4.2 Backwashing

Consistent with the Filter Backwash Recycling Rule, the filter backwash from the second stage (as well as the first stage) must be recycled to the head of the plant if it is recycled. The existing backwashing capacity may be limited and need to be increased. There may be insufficient finished water storage to supply backwash water or there may need to be additional pumping capacity, depending upon the design of the additional filtration stage (e.g., if the existing filters have a small area and the new filters are significantly larger, the existing backwash pumps may not be able to supply

water at a high enough flow to properly expand the filter bed). It is likely that the second stage filters would need to be backwashed less frequently than the first stage ones, due to the lower solids loading.

Filter ripening and/or filter-to-waste times for the second filtration stage will most likely differ from the first stage.

9.4.3 Turbidity Monitoring

EPA recommends monitoring the turbidity of the individual filters in the second stage in order to be able to identify any possible filter upset situations. Depending on the first filtration stage effluent quality, it may be difficult to see a significant difference in the second stage effluent. If the combined second stage filter effluent is the only process stream monitored, it is unlikely that an upset in one second stage filter could be detected.

10.0 Chlorine Dioxide

10.1 Introduction

Chlorine dioxide is used for disinfection, taste and odor control, and iron and manganese removal. Chlorine dioxide is effective for inactivation of bacteria, viruses, and protozoa, including *Cryptosporidium* while forming fewer halogenated byproducts than chlorine. It is stable only in dilute aqueous solutions and must be generated on-site. It can be generated using a variety of starting materials including chloride, chlorite, or chlorate.

The Surface Water Treatment Rule (SWTR) and subsequent Stage 1 Disinfection Byproducts Rule (Stage 1 DBPR) and Interim Enhanced Surface Water Treatment Rule (IESWTR) all recognize the ability of chlorine dioxide to inactivate pathogens. As a result, there is much information and guidance available on the application of chlorine dioxide for disinfection, particularly in the following two guidance manuals:

- *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources* (USEPA 1991) (commonly referred to as the Surface Water Treatment Rule Guidance Manual).
 - Describes how to calculate the CT value (CT is described in the next sub-section) for a given disinfectant, including methodologies for determining the residual concentration (C) and contact time (T).
 - Includes CT values for log-inactivation of *Giardia* and viruses.
- *Alternative Disinfectants and Oxidants Guidance Manual* (USEPA 1999).
 - Provides full descriptions of:
 - chlorine dioxide chemistry
 - on-site generation
 - primary uses and points of applications
 - pathogen inactivation and disinfection efficiency
 - byproduct production
 - analytical methods
 - operational considerations

The SWTR and Alternative Disinfectants and Oxidants Guidance Manuals are available on EPA's website, <http://www.epa.gov/safewater/mdbp/implement.html>.

The purpose of this chapter is to (1) describe what systems need to do to achieve *Cryptosporidium* inactivation treatment credit for disinfecting with chlorine dioxide, (2) discuss design and operational considerations that will assist water systems in deciding whether this toolbox option is a practical option for them, and (3) discuss key issues associated with using chlorine dioxide as a disinfectant. This chapter is organized as follows:

- 10.2 Log Inactivation Requirements - describes the concentration and time variables of the CT parameter, presents the chlorine dioxide CT table for *Cryptosporidium*, and provides a sample CT calculation.
- 10.3 Monitoring Requirements - describes monitoring requirements of both LT2ESWTR and Stage 1 DBPR.
- 10.4 Unfiltered Systems LT2ESWTR Requirements - describes the level of *Cryptosporidium* inactivation unfiltered systems must provide, and monitoring requirements that must be met.
- 10.5 Disinfection with Chlorine Dioxide - describes chlorine dioxide chemistry and disinfection with chlorine dioxide.
- 10.6 Toolbox Selection Considerations - discusses the advantages and disadvantages of disinfection with chlorine dioxide.
- 10.7 Design Considerations - discusses effects of temperature and the point of chlorine dioxide addition on achieving the required CT value.
- 10.8 Operational Considerations - discusses water quality parameters that affect the disinfection ability of chlorine dioxide.
- 10.9 Safety Issues - describes considerations for chemical storage and discusses the acute health risks of chlorine dioxide.

10.2 Log Inactivation Requirements

Systems can achieve anywhere from 0.5 to 3.0 log *Cryptosporidium* inactivation with the addition of chlorine dioxide. The amount of *Cryptosporidium* inactivation credit a system may receive is determined by the CT provided in the treatment process (40 CFR 141.729(b)). This methodology provides a conservative characterization of the dose of chlorine dioxide necessary to achieve a

specified inactivation level of *Cryptosporidium*. CT is the product of the disinfectant concentration and disinfectant contact time and is defined in the LT2ESWTR (40 CFR 141.729(a)):

$$CT = \text{Disinfectant (mg/L)} \times \text{Contact Time (minutes)}$$

- “T” is the time (in minutes) it takes the water, during peak hourly flow, to move from the point of disinfectant application to a point where, C, residual concentration is measured prior to the first customer, or between points of residual measurement.
- “C” is the concentration of chlorine dioxide present in the system, expressed in mg/L.

The concept of regulating surface water treatment disinfection processes through CT was first introduced in the SWTR. Tables of *Giardia* and virus log inactivations correlated to CT values, commonly referred to as CT tables, were presented in the SWTR Guidance Manual. For the LT2ESWTR, EPA developed CT tables for the inactivation of *Cryptosporidium*. Alternatively, a system may conduct a site-specific study to determine the CT values necessary to meet a specified log inactivation, using State approval (40 CFR 141.729(b)(4)). Appendix A provides guidance for conducting a site-specific study.

10.2.1 CT Calculation

The methodology and calculations for determining CT have not changed from the SWTR to the LT2ESWTR requirements. This section briefly reviews how CT is used to determine log-inactivation for the SWTR and presents the chlorine dioxide CT table for *Cryptosporidium* inactivation. Refer to the SWTR Guidance Manual for descriptions of measuring C and determining T.

Summary of CT Determination and Corresponding Log-inactivation as Presented in the SWTR Guidance Manual

CT can be calculated for an entire treatment process or broken into segments and summed for a total CT value. C is measured at the end of a given segment. T is generally estimated by methods involving established criteria (flow, volume, and contactor geometry) or tracer studies. The following steps describe the CT calculation from measured C and T values for a segment of the entire treatment process:

- 1) Calculate CT_{calc} by multiplying the measured C and T values.
- 2) From the CT tables, find the CT value for the log inactivation desired, this is CT_{table} .

- 3) Calculate the ratio of $CT_{\text{calc}}/CT_{\text{table}}$ for each segment.
- 4) If a system has multiple segments, sum the $CT_{\text{calc}}/CT_{\text{table}}$ ratios for a total inactivation ratio.
- 5) If the ratio of $CT_{\text{calc}}/CT_{\text{table}}$ is at least 1, then the treatment process provides the log inactivation that the CT_{table} represents (log inactivation desired from step #2).

Table 10.1 CT Values (mg-min/l) for *Cryptosporidium* Inactivation by ClO_2

Log credit	Water Temperature, °C ¹									
	<=0.5	1	2	3	5	7	10	15	20	25
0.5	319	305	279	256	214	180	138	89	58	38
1.0	637	610	558	511	429	360	277	179	116	75
1.5	956	915	838	767	643	539	415	268	174	113
2.0	1275	1220	1117	1023	858	719	553	357	232	150
2.5	1594	1525	1396	1278	1072	899	691	447	289	188
3.0	1912	1830	1675	1534	1286	1079	830	536	347	226

¹CT values between the indicated temperatures may be determined by interpolation

Example CT Calculation

A plant draws 1.5 MGD of 5 degrees Celsius water from a stream, adding 1.8 mg/l of chlorine dioxide at the intake. The water travels through 2 miles of 12 inch pipe to a settling tank. The detention time in the tank, as determined by a tracer study, is 150 minutes. After the tank, it travels through another 12-inch pipe to the plant. Figure 10.1 provides a schematic of an intake, piping, and tank. The concentration of chlorine dioxide at each point is measured as follows:

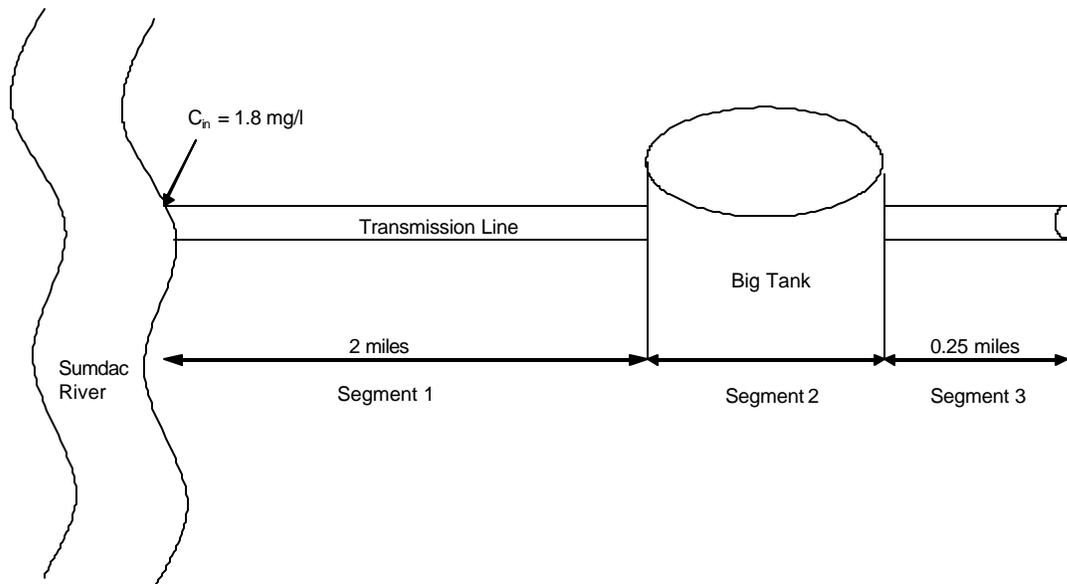
$$C_{\text{initial}} = 1.8 \text{ mg/l}$$

$$C_{\text{entering tank}} = 1.6 \text{ mg/l}$$

$$C_{\text{leaving tank}} = 0.8 \text{ mg/l}$$

$$C_{\text{leaving 2nd pipe}} = 0.2 \text{ mg/l}$$

Figure 10.1 CT Calculation Example Schematic



The residence times of the two sections of pipe are determined assuming plug flow. Therefore the time for each section is calculated as follows:

$$T_1 = (A_1 * L_1 / Q_1) = (\pi r^2 L_1 / Q_1) * (7.48 \text{ gal./1 ft.}^3) * (\text{MG}/1,000,000 \text{ gal.}) * (1,440 \text{ min./day})$$

where:

- A is the cross-sectional area of the pipe in square feet
- Q is the volumetric flow rate in MGD
- L is the length of pipe in feet
- r is the radius of the pipe in feet.

Therefore the times for the two sections of the pipe are as follows:

$$T_1 = 2 \text{ mi.} * (5,280 \text{ ft./mi.}) * \pi * (0.5 \text{ ft.})^2 * (0.0108 \text{ MG*sec/ft.}^3 * \text{day}) / (1.5 \text{ MGD}) = 59.7 \text{ min.}$$

$$T_3 = 0.25 \text{ mi.} * (5,280 \text{ ft./mi.}) * \pi * (0.5 \text{ ft.})^2 * (0.0108 \text{ MG*sec/ft.}^3 * \text{day}) / (1.5 \text{ MGD}) = 7.4 \text{ min.}$$

The T_{10} , or time for 90 percent of a tracer to pass through the section for the tank is as follows:

$$T_2 = 150 \text{ minutes}$$

CT Calculation:

Step 1. Calculate CT for each segment.

The concentrations and times for each segment are known. The T's are calculated above and the C is the concentration measured at the end of each segment. The CT for each segment is calculated as follows:

$$CT_1 = (1.6 \text{ mg/l}) \times (59.5 \text{ min.}) = 95.2 \text{ mg} \times \text{min./l}$$

$$CT_2 = (0.8 \text{ mg/l}) \times (150 \text{ min.}) = 120 \text{ mg} \times \text{min./l}$$

$$CT_3 = (0.2 \text{ mg/l}) \times (7.4 \text{ min.}) = 1.5 \text{ mg} \times \text{min./l}$$

Step 2. Look up CT_{table} in Table 10.1. For 5°C and 0.5 log inactivation,

$$CT_{\text{table}} = 214 \text{ mg} \times \text{min./l.}$$

Step 3. Calculate the ratio of $CT_{\text{calc}}/CT_{\text{table}}$ for each segment.

$$(CT_{\text{calc}}/CT_{\text{table}})_1 = 95.2/214 = 0.44$$

$$(CT_{\text{calc}}/CT_{\text{table}})_2 = 120/214 = 0.56$$

$$(CT_{\text{calc}}/CT_{\text{table}})_3 = 1.5/214 = 0.01$$

Step 4. Sum the $CT_{\text{calc}}/CT_{\text{table}}$ for each segment.

$$(CT_{\text{calc}}/CT_{\text{table}})_{\text{total}} = 0.44 + 0.56 + 0.01 = 1.01$$

Determine Log Inactivation:

If the result of Step 4 is greater than 1, the log inactivation associated with the CT_{table} values is achieved. If the result is less than 1, that level of log inactivation is not achieved (if the log inactivation was less than 1.0, the calculations should be repeated at a lower log inactivation). In this example, the sum of the $CT_{\text{calc}}/CT_{\text{table}}$ for all the segments is greater than 1, so the system qualifies for a 0.5 log *Cryptosporidium* inactivation.

10.3 Monitoring Requirements

10.3.1 LT2ESWTR

The LT2ESWTR requires **daily CT monitoring** (40 CFR 141.730), which must be done **during peak hourly flow**. Since systems may not know when the peak hourly flow will occur, EPA recommends monitoring on an hourly basis. Contact time does not have to be determined on a daily basis, only concentration does. Contact time is determined using the peak hourly flow. Systems should reevaluate contact time whenever they modify a process and the hydraulics are affected (e.g., add a pump for increased flow, reconfigure piping).

The chlorine dioxide concentration should be measured using approved analytical methods, either DPD, (Standard Method 4500-ClO₂ D) or Amperometric Method II, (Standard Method 4500-ClO₂ E). Details on these methods can be found in *Standard Methods for the Examination of Water and Wastewater*, 20th edition, American Public Health Association, 1998.

Note, if a system is required to develop a disinfection profile under the LT2ESWTR and changes its disinfection process, the LT2ESWTR requires the system to calculate a disinfection profile and benchmark (40 CFR 141.714(a)) (see Chapter 1, section 1.6 for details).

10.3.2 Stage 1 DBPR

The Stage 1 DBPR requires all systems using chlorine dioxide for disinfection or oxidation to monitor daily for chlorine dioxide and chlorite at the distribution system entry point. In addition, systems must take monthly chlorite samples at three locations in the distribution system. Table 10.2 lists the chlorine dioxide and chlorite distribution system monitoring requirements.

Table 10.2 Distribution System Monitoring Requirements at Each Plant

Location	Frequency
Chlorite	
Distribution System Entry Point	Daily
Distribution System Sample Set of 3: 1 Near First Customer 1 In Middle of the Distribution System 1 At Maximum Residence Time	Monthly
Chlorine Dioxide	
Distribution System Entry Point	Daily

If the chlorine dioxide maximum residual disinfectant level (MRDL) of 0.8 mg/L or the chlorite maximum contaminant level (MCL) of 1.0 mg/L is exceeded in any of the samples, additional monitoring is required (see the Stage 1 DBPR, 40 CFR 141.132(b) for further information). The monthly monitoring requirements for chlorite may be reduced if all chlorite samples are below the MCL for a 1-year period.

10.4 Unfiltered System LT2ESWTR Requirements

The LT2ESWTR requires unfiltered systems to provide at least 2.0 log *Cryptosporidium* inactivation (40 CFR 141.721(b)). If their source water *Cryptosporidium* concentration is greater than 0.01 oocyst/liter, then systems must provide 3.0 log *Cryptosporidium* inactivation (40 CFR 141.721(b)). The requirements of the previous SWTR regulations still apply— achieve 3 log inactivation of *Giardia* and 4 log inactivation of viruses and maintain a disinfectant residual in the distribution system (e.g., free chlorine or chloramines). LT2ESWTR also requires that a minimum of two disinfectants be used to meet overall disinfection requirements.

The monitoring requirements described in section 10.3 apply to unfiltered systems. Additionally, the LT2ESWTR requires unfiltered systems to meet the *Cryptosporidium* log-inactivation requirements determined by the daily CT value every day the system serves water to the public, except one day per calendar month (40 CFR 141.721(c)). Therefore, if an unfiltered system fails to meet *Cryptosporidium* log-inactivation two days in a month, it is in violation of the treatment technique requirement.

10.5 Disinfection With Chlorine Dioxide

Chlorine dioxide (ClO_2) is an uncharged compound of chlorine in the +IV oxidation state. It is a relatively small, volatile, and highly energetic molecule, and a free radical even in dilute aqueous solutions. At high concentrations, it reacts violently with reducing agents. However, it is stable in dilute solution in a closed container in the absence of light. When an aqueous solution is open to the atmosphere, chlorine dioxide readily comes out of solution. Aqueous solutions of chlorine dioxide are also susceptible to photolytic decomposition, depending on the time of exposure and intensity of UV light.

Disinfection of protozoa is believed to occur by oxidation reactions disrupting the permeability of the cell wall (Aieta and Berg 1986). Chlorine dioxide functions as a highly selective oxidant due to its unique, one-electron transfer mechanism where it is reduced to chlorite (ClO_2^-) (Hoehn et al. 1996).

In drinking water, chlorite (ClO_2^-) is the predominant reaction end product, with approximately 50 to 70 percent of the chlorine dioxide converted to chlorite and 30 percent to chlorate (ClO_3^-) and chloride (Cl^-) (Werdehoff and Singer 1987). This has a significant impact on disinfection capabilities for drinking water, since chlorite is a regulated drinking water contaminant with an MCL of 1.0 mg/L. Based on a 50 to 70 percent conversion of chlorine dioxide to chlorite, the maximum dose is limited to 1.4 to 2.0 mg/l unless the chlorite is removed through subsequent treatment processes.

10.6 Toolbox Selection Considerations

10.6.1 Advantages

There are several advantages to using chlorine dioxide as a primary disinfectant. Chlorine dioxide is approximately four times as effective as chlorine for the inactivation of *Giardia* and is a stronger disinfectant than chlorine for bacteria (White 1999). However, free chlorine is more effective for the inactivation of viruses. Other advantages of disinfection with chlorine dioxide include:

- A high oxidizing potential allows it to oxidize other compounds such as manganese and some taste and odor compounds.
- Chlorine dioxide does not form regulated halogenated organic byproducts.
- The effect of pH on the disinfection ability of chlorine dioxide is much smaller than for other disinfectants.
- Chlorine dioxide has shown a synergistic effect when combined with other disinfectants such as ozone, chlorine, and chloramines that leads to greater inactivation with the disinfectants added in series than by either disinfectant individually.

10.6.2 Disadvantages

A major disadvantage of chlorine dioxide is the byproduct formation of chlorite and chlorate. Section 10.6 describes the dose limits of chlorine dioxide due to the formation of chlorite. Other disadvantages of disinfection with chlorine dioxide include:

- Difficulty in maintaining an effective residual. Additionally, residual will be lost in the filters.
- It decomposes upon exposure to sunlight, fluorescent light bulbs, and UV disinfection systems.

- Ability to disinfect is reduced under colder temperatures.
- If the ratio of reactants in the chlorine dioxide generator is incorrect, excess aqueous chlorine can remain, which can form halogenated disinfection byproducts.
- Chlorine dioxide must be generated on-site.
- There may be a need for three-phase power which may not be compatible with some water systems.
- Chlorine dioxide can be explosive at high temperatures or pressures.
- Storage of sodium chlorite solution can be problematic due to crystallization at low temperatures or high concentrations and stratification at temperatures below 40°F (or 4°C).
- High cost of chemicals.
- Dialysis patients are sensitive to higher chlorite levels and should be notified if chlorine dioxide is going to be added where it has not routinely been used.
- Training, sampling, and analysis costs are high.

Systems considering using chlorine dioxide as a disinfectant should perform chlorine dioxide demand/decay tests on the water being considered for disinfection (raw water or filter effluent) under normal and poor water quality conditions. If chlorine dioxide is added where the demand is 1.4 mg/l or greater, the system may have difficulty complying with the chlorite MCL. If the raw water has a chlorine dioxide requirement greater than 1.4 mg/l, chlorine dioxide might still be able to be used for post disinfection since the oxidant demand will be less after the filters.

10.7 Design Considerations

10.7.1 Designing to Lowest Temperature

As the water temperature declines, chlorine dioxide becomes less effective as a disinfectant. LeChevallier et al. (1997) found that reducing the temperature from 20 degrees Celsius to 10 degrees Celsius reduced disinfection effectiveness by 40 percent. Since the treatment achieved for chlorine dioxide addition is temperature dependent, systems need to consider the variability in water

temperature to ensure they meet the CT level for the minimum treatment needed for compliance. For example, if a system is required to provide an additional 1 log *Cryptosporidium* treatment and plans to achieve that with chlorine dioxide alone, then it should determine the CT required for the lowest water temperature experienced and ensure it can meet those CT requirements.

10.7.2 Point of Addition

There are two main considerations for determining locations of chlorine dioxide addition for the purpose of *Cryptosporidium* inactivation—contact time and chlorine dioxide demand. Additionally, systems using ozone should consider that ozone will degrade chlorine dioxide. The application point for chlorine dioxide should be well upstream of the ozone process or just after the ozone process.

Contact Time

There must be substantial contact time with a residual concentration. The CT requirements for *Cryptosporidium* are much higher than for *Giardia* and viruses and when designing to the lowest water temperatures, the resulting contact time requirements are relatively high for even the 0.5 and 1.0 log inactivation. Chlorine dioxide readily degrades when exposed to light from fluorescent lamps or the sun, therefore all the available concentration in open basins will most likely not be utilized for disinfection. For most systems, the point of application will be either at the raw water intake or after the filters, whichever can provide the necessary contact time.

Oxidant Demand

The oxidant demand of the water affects chlorite and chlorate byproduct formation (section 10.6). If the chlorine dioxide requirement of the raw water is greater than 1.4 mg/L then chlorite concentration will likely exceed the MCL. However, chlorine dioxide could be added after the filters where the oxidant demand is frequently lower and, therefore, a lower dose of chlorine dioxide would result in a lower byproduct concentration of chlorite.

10.8 Operational Considerations

Of all the water quality parameters, water temperature has the strongest effect on the disinfection ability of chlorine dioxide. The concentration of suspended matter and pH also have an effect, but to a lesser extent than temperature. Although the disinfection potential of chlorine dioxide is not strongly affected by pH, studies have shown that chlorine dioxide disinfection is better under higher pH (LeChevallier et al. 1997).

Suspended matter and pathogen aggregation affect the disinfection efficiency of chlorine dioxide. Protection from chlorine dioxide inactivation due to bentonite was determined to be approximately 11 percent for water with turbidity values less than or equal to 5 NTU and 25 percent for turbidity between 5 and 17 NTUs (Chen et al. 1984).

Based on the research discussed above, the optimal conditions for *Cryptosporidium* disinfection with chlorine dioxide are low turbidity, high pH, and high temperature.

10.9 Safety Issues

Because chlorine dioxide can be explosive and pose acute health risks to those exposed to gaseous chlorine dioxide, a safety plan should be developed that includes precautions for generation, handling, storage, and emergency response.

Airborne concentrations greater than 10 percent may cause explosions.

10.9.1 Chemical Storage

Most chlorine dioxide generators use sodium chlorite solutions as a raw material. If sodium chlorite solutions are accidentally acidified or exposed to a reducing agent, uncontrolled production and release of gaseous chlorine dioxide can result. In addition to being toxic, if the gaseous chlorine dioxide reaches concentrations greater than 10 percent, it can spontaneously explode.

Sodium chlorite should be stored away from other chemicals, particularly any acid solutions or chemicals that could act as reducing agents. Construction materials in sodium chlorite storage areas, as well as chlorine dioxide generating areas, should be fire resistant such as concrete. Sodium chlorite fires burn especially hot and produce oxygen as a byproduct, so special fire fighting techniques are required to extinguish the fire. These firefighting techniques should be part of the safety plan and proper equipment and supplies should be stored nearby. Temperatures in storage and generation areas should be kept below 130 degrees Celsius.

10.9.2 Acute Health Risks of Chlorine Dioxide

Exposure to gaseous chlorine dioxide can cause shortness of breath, coughing, respiratory distress, and pulmonary edema. The Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) is 0.1 ppm. Areas where chlorine dioxide is generated and stored should have appropriate monitoring to detect leaks of chlorine dioxide or other chlorine containing chemicals into the air. Proper ventilation and scrubbing systems should be installed. First aid kits and

respirators should also be accessible outside the building. Operators should be trained to use the respirators.

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11.0 Ozone

11.1 Introduction

Ozone is commonly used in drinking water treatment for disinfection and taste and odor control. Ozone is a strong oxidant that can inactivate microorganisms, including *Cryptosporidium*, and also oxidize and break down natural organic matter. It exists as a gas at room temperature and must be generated on-site. Ozone reacts rapidly with organic and inorganic compounds and does not maintain a residual over the time scales associated with secondary disinfection.

The Surface Water Treatment Rule (SWTR) and subsequent Stage 1 Disinfectants and Disinfection Byproducts Rule (DBPR) and Interim Enhanced SWTR (IESWTR) all recognize the capability of ozone to inactivate pathogens. As a result, there is much information and guidance available on the application of ozone for disinfection, particularly in the following two guidance manuals:

- *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources* (USEPA 1991) (commonly referred to as the *Surface Water Treatment Rule Guidance Manual*).
 - Describes how to calculate the CT value for ozone (CT is described in the next section), including methodologies for determining the residual concentration (C) and contact time (T).
 - Includes ozone CT values for log-inactivation of *Giardia* and viruses.
- *Alternative Disinfectants and Oxidants Guidance Manual* (USEPA,1999).
 - Provides full descriptions of:
 - ozone chemistry
 - on-site generation
 - primary uses and points of application
 - byproduct production
 - analytical methods
 - operational considerations

The *Surface Water Treatment Rule Guidance Manual* and *Alternative Disinfectants and Oxidants Guidance Manual* are available on EPA's website:

The purpose of this chapter is to (1) describe what systems need to do to receive *Cryptosporidium* treatment credit for disinfecting with ozone, (2) discuss design and operational considerations that will assist water systems in deciding whether this toolbox option is a practical option for their system, and (3) discuss key issues associated with using ozone as a disinfectant. This chapter is organized as follows:

- 11.2 Credits - discusses *Cryptosporidium* inactivation credit systems can receive with the addition of ozone, and relates CT to *Cryptosporidium* inactivation credit.
- 11.3 CT Determination - summarizes how CT is used to determine log inactivation credit for the SWTR and highlights the changes in CT calculation methodologies from the SWTR to the LT2ESWTR.
- 11.4 Monitoring Requirements - discusses monitoring requirements of both LT2ESWTR and Stage 1 DBPR.
- 11.5 Unfiltered Systems LT2ESWTR Requirements - discusses *Cryptosporidium* inactivation requirements that unfiltered systems must meet.
- 11.6 Toolbox Selection - discusses the potential advantages and disadvantages of ozone processes.
- 11.7 Disinfection with Ozone - describes reaction pathways of ozone in water, and inorganic and organic byproduct formation.
- 11.8 Design - discusses similarities and differences of different types of ozone generators and contactors, general considerations in determining the locations of ozone addition, and filter media and operating conditions of biologically active filters.
- 11.9 Safety Considerations in Design - discusses various safety considerations that should be taken into account in the design of ozone generators.
- 11.10 Operational Issues - discusses how ozone disinfection and CT calculation are affected by ozone demand, pH, temperature, and residual disinfectant in the distribution system.

11.2 Credits

Systems can receive between a 0.5 to 3.0 log *Cryptosporidium* inactivation credit with the addition of ozone, depending on the ozone dose applied. The value of the *Cryptosporidium*

inactivation credit that a system receives is determined by the CT or inactivation provided in the treatment process. CT values are established to provide a conservative characterization of the dose of ozone necessary to achieve a specified inactivation of *Cryptosporidium*. CT is defined as the product of the disinfectant concentration and disinfectant contact time:

$$CT = \text{Disinfectant (mg/L)} \times \text{Contact Time (minutes)}$$

- “T” is the time it takes the water to move from the point where the initial disinfectant residual concentration is measured to the point where the final disinfectant residual concentration is measured in a specified disinfectant segment
- “C” is the measured concentration of dissolved ozone in mg/L

The concept of regulating surface water treatment disinfection through CT was first introduced in the SWTR. Tables relating *Giardia* and virus log inactivations with associated CT values, commonly referred to as CT tables, were presented in the SWTR Guidance Manual. For the LT2ESWTR, EPA developed CT values for *Cryptosporidium* inactivation by ozone (Table 11.1).

Table 11.1 CT Values for *Cryptosporidium* Inactivation by Ozone (40 CFR 141.730)

Log credit	Water Temperature, °C ¹									
	≤0.5	1	2	3	5	7	10	15	20	25
0.5	12	12	10	9.5	7.9	6.5	4.9	3.1	2.0	1.2
1.0	24	23	21	19	16	13	9.9	6.2	3.9	2.5
1.5	36	35	31	29	24	20	15	9.3	5.9	3.7
2.0	48	46	42	38	32	26	20	12	7.8	4.9
2.5	60	58	52	48	40	33	25	16	9.8	6.2
3.0	72	69	63	57	47	39	30	19	12	7.4

¹CT values between the indicated temperatures may be determined by interpolation.

If a utility believes that the CT values presented in Table 11.1 do not accurately represent the conditions needed to achieve the desired level of inactivation in their system, they have the option of conducting a site specific study to generate a set of CT tables for their facility. The study would involve measuring actual *Cryptosporidium* inactivation performance under site conditions. If accepted by the State, the CT tables generated by the site study would replace the tables given in this guidance for the site at which the study was performed. Guidance on site specific studies of *Cryptosporidium* inactivation is presented in Appendix A.

11.3 CT Determination

The recommended methodologies and calculations for determining CT have two modifications from the SWTR to the LT2ESWTR.

- For *Cryptosporidium*, EPA recommends that **no inactivation credit** be granted for the first dissolution chamber due to the higher CT requirements of *Cryptosporidium* compared to *Giardia* and virus. (This differs from the SWTR guidance manual, where EPA recommends granting inactivation *Giardia* and virus credit for first chamber of an ozone contactor, provided that the residual ozone concentration measured at the outlet from the first contact chamber met minimum concentration levels.) The relatively small CT values normally achieved due to oxidant demand in the first dissolution chamber and the resources required for routine ozone monitoring would likely offset the benefit from the small *Cryptosporidium* credit achieved.
- If no tracer study data are available for determining T, EPA recommends using the continuous stirred tank reactor (CSTR) approach (described below) or the Extended-CSTR approach (described in Appendix B). The T_{10}/T ratios based on baffling characteristics presented in Table C-5 of the SWTR Guidance Manual are based on hydraulic studies of clearwells and basins. At this time, EPA is not aware of similar studies for ozone contactors that could be used to develop comparable recommendations.

This guidance manual presents three methods for calculating CT:

- T_{10}
- Continuous stirred tank reactor (CSTR)
- Extended-CSTR

These methods differ in the level of effort associated with them and, in general, the ozone dose required to achieve a given level of inactivation. Selecting the appropriate method(s) to use depends on the configuration of the ozone contactor and amount of process evaluation and monitoring that a system wishes to undertake. Combinations of two or more methods may also be used. For example, contactors with multiple segments may have one or two segments with their CT calculated using either the T_{10} or CSTR methods, while the CT for the remaining segment is calculated using the Extended-CSTR approach. The T_{10} and CSTR are the simplest methods and are described in this chapter. Appendix B provides more information for choosing the appropriate method and detailed guidance for the Extended-CSTR method. A fourth method, the Segmented Flow Analysis approach, is under consideration by EPA, but the details of the approach are not final. EPA is requesting comment on the approach and any appropriate safety factors to ensure the inactivation credit calculated using the

method is actually achieved (see section 11.11 for comment requests). Table 11.2 summarizes the current methods, including describing the situations when their use is appropriate.

Table 11.2 Applicable Methods and Terminology for Calculating the Log-Inactivation Credit

	Section Description	Terminology	Method for Calculating Log-Inactivation	Restrictions
No Tracer Data	Chambers where ozone is added			
	First chamber	First Dissolution Chamber	No log-inactivation credit is recommended	None
	Other chambers	Co-Current or Counter-Current Dissolution Chambers	CSTR Method in each chamber with a measured effluent ozone residual concentration	No credit is given to a dissolution chamber unless a detectable ozone residual has been measured upstream of this chamber
	Reactive Chambers			
	≥ 3 consecutive chambers	Extended-CSTR Zone	Extended-CSTR Method in each chamber	Detectable ozone residual should be present in at least 3 chambers in this zone, measured via in-situ sample ports. Otherwise, the CSTR method should be applied individually to each chamber having a measured ozone residual
	< 3 consecutive chambers	CSTR Reactive Chamber(s)	CSTR Method in each chamber	None
No Tracer Data	Chambers where ozone is added			
	First chamber	First Dissolution Chamber	No log-inactivation is credited to this section	Not applicable
	Other chambers	Co-Current or Counter-Current Dissolution Chambers	T ₁₀ or CSTR Method in each chamber with a measured effluent ozone residual concentration	No credit will be given to a dissolution chamber unless a detectable ozone residual has been measured upstream of this chamber
	Reactive Chambers			

≥ 3 consecutive chambers	Extended-CSTR Zone	Extended-CSTR Method in each chamber	Detectable ozone residual should be present in at least 3 chambers in this zone, measured via in-situ sample ports. Otherwise, the T10 or CSTR method should be applied to each chamber having a measured ozone residual
< 3 consecutive chambers	T ₁₀ or CSTR Reactive Chamber(s)	T ₁₀ or CSTR Method in each chamber	None

The remainder of this section describes how to calculate C for the T₁₀ and CSTR methods and then describes the T₁₀ and CSTR methodologies.

11.3.1 Measuring C for T₁₀ and CSTR Methods

The methods for determining C have not been modified from those presented in the SWTR Guidance Manual. The two methods for determining C are:

- 1) Direct measure of the concentration profile of dissolved ozone in each contact chamber (described in section O.3.2 of the SWTR Guidance Manual)
- 2) Indirect prediction of the average C based on dissolved ozone measurements at the contact chamber outlet (described in section O.3.3 of the SWTR Guidance Manual)

For the second method, predicting the average C based on outlet measurements, the correlations presented in Table 11.3 are to be used for estimating C based on C_{in} and C_{out} measurements, based on the flow configuration within the contact chamber. To be granted inactivation credit for a chamber, its final ozone concentration should be above the detection limit (i.e., have a positive C_{out} value).

Table 11.3 Correlations to Predict C* Based on Outlet Concentration

Turbine	Co-Current Flow	Counter-Current Flow	Reactive Flow
C_{out}	C_{out} or $(C_{in}+C_{out})/2$	$C_{out}/2$	C_{out}

* C - Characteristic concentration, used for CT calculation

C_{out} - Ozone residual concentration at the outlet from the chamber

C_{in} - Ozone residual concentration at the inlet to the chamber

11.3.2 T_{10} Method

The T_{10} method is appropriate for contactors with hydraulic conditions resembling plug flow. Using the T_{10} approach, the contact time (T) is the time at which 90 percent of the water in the contactor or segment has passed through the contactor. EPA recommends that tracer studies be used to determine the T_{10} for ozone contactors. The SWTR Guidance Manual describes how to conduct a tracer test.

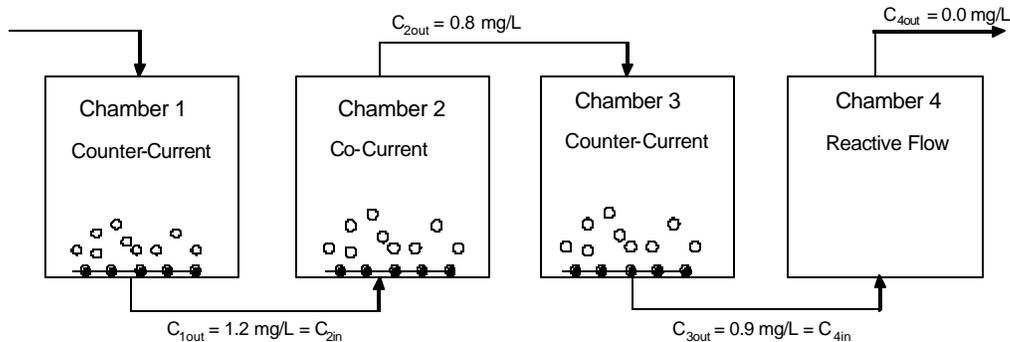
CT can be calculated for an entire treatment process (e.g., an entire ozone contactor) or broken into segments (e.g., individual contact chambers) and summed for a total CT value for all segments. C is measured either at the end of a given segment or both the beginning and end of the segment.

The following steps describe the CT calculation from measured C and T values for a segment or the entire treatment process:

- 1) Calculate CT_{calc} by multiplying the measured C and T values.
- 2) From the CT table (Table 11.1), find the CT value for the log inactivation credit desired, this is CT_{table} .
- 3) Calculate the ratio of CT_{calc}/CT_{table} for each segment.
- 4) If a system has multiple segments, sum the CT_{calc}/CT_{table} ratios for a total inactivation ratio.
- 5) If the ratio of CT_{calc}/CT_{table} is at least 1, then the treatment process provides the level of log inactivation that CT_{table} represents (log inactivation credit desired from step #2).

Example CT Calculation and Log Credit Determination using the T_{10} Method

A water system employs a 4 chamber ozone contactor to achieve a 0.5-log *Cryptosporidium* inactivation credit. The contactor is designed and operated as shown in the following diagram.



The water temperature is 5 degrees Celsius. Each chamber has a volume of 1,000 gallons. Results from a tracer test showed the T_{10} for the entire contactor (i.e. through all 4 chambers) was 24 minutes.

The first step is to determine the ozone concentration for each chamber (segment). EPA recommends that inactivation credit not be granted for the first chamber, therefore concentrations are only calculated for Chambers 2, 3, and 4. Using Table 11.2, C can be determined with the following equations:

Chamber 2	$C = (C_{in} + C_{out}) / 2$ or $C = C_{out}$
Chamber 3	$C = C_{out} / 2$
Chamber 4	$C = C_{out}$

Therefore for:

Chamber 2:	$C = (1.2 + 0.8) / 2 = 1.0 \text{ mg/L}$ (this equation gives the higher C value)
Chamber 3:	$C = 0.9 / 2 = 0.45 \text{ mg/L}$
Chamber 4:	$C = 0.0 \text{ mg/l}$

2) Calculate the T for each chamber.

The T_{10} of all four chambers is divided proportionally by volume among the four chambers. This method cannot be used if the chambers with final concentrations of zero (non-detectable) are 50 percent or greater than the entire volume of the chambers. Only the last chamber had a non-detectable

final concentration and that chamber is 25 percent the volume of all the chambers. Therefore the T_{10} can be extrapolated among the chambers to estimate individual T_{10} values.

$$T_{10} \text{ of each chamber} = T_{10}(V_{1-4}/V_T) = 24(1,000 \text{ gallons}/4,000 \text{ gallons}) = 6 \text{ min.}$$

(In this example, the volume of each chamber is same therefore the T_{10} of each chamber is simply one-fourth of the total T_{10} .)

3) Calculate the CT for each chamber

Chamber 1: not calculated

$$\text{Chamber 2: } CT = 1.0 \text{ mg/L} \times 6 \text{ min} = 6.0 \text{ mg-min/L}$$

$$\text{Chamber 3: } CT = 0.45 \text{ mg/L} \times 6 \text{ min} = 2.7 \text{ mg-min/L}$$

$$\text{Chamber 4: } CT = 0 \text{ mg/L} \times 6 \text{ min} = 0 \text{ mg-min/L}$$

4) Identify the CT_{table} for the log inactivation credit desired for each chamber. Calculate the ratio of CT_{calc} to CT_{table} , and sum the ratios to get a total log inactivation ratio.

	CT_{calc}	CT_{table} for 0.5-log	Ratio of $CT_{\text{calc}} / CT_{\text{table}}$
Chamber 2	6.0	7.9	0.76
Chamber 3	2.7	7.9	0.34
Chamber 4	0	7.9	-
Total Log Inactivation Ratio			1.10

The log inactivation ratio is at least 1, therefore this system achieves 0.5 log *Cryptosporidium* inactivation credit.

11.3.3 CSTR Method

The CSTR method is recommended for contactors that experience significant back mixing or when no tracer data is available. This method uses the hydraulic detention time of the ozone contactor, as described below, for estimating the contact time. The CSTR method should be applied to the individual chambers in the contactor.

For the CSTR approach, the CT table is not directly used and instead log inactivation is calculated with the following equation:

$$-\text{Log}(I/I_0) = \text{Log}(1 + 2.303k_{10} \times C \times \text{HDT}) \quad \text{Equation 11-1}$$

where:

$-\text{Log}(I/I_0)$ = the log inactivation

k_{10} = log base ten inactivation coefficient (L/mg-min)¹

C = Concentration from Table 11-2 (mg/L)

HDT = Hydraulic detention time (minutes)

Table 11.4 presents the k_{10} values for *Cryptosporidium* (k_{10} values are calculated from the CT table).

Table 11.4 Inactivation Coefficients for *Cryptosporidium*, Log base 10 (L/mg-min)

	Water Temperature, °C									
	≤0.5	1	2	3	5	7	10	15	20	25
k_{10}	0.0417	0.0430	0.0482	0.0524	0.0629	0.0764	0.101	0.161	0.254	0.407

To interpolate between the temperatures in the table, the following equation can be used:

$$k_{10} = 0.0397 \times (1.09757)^T \quad \text{Equation 11-2}$$

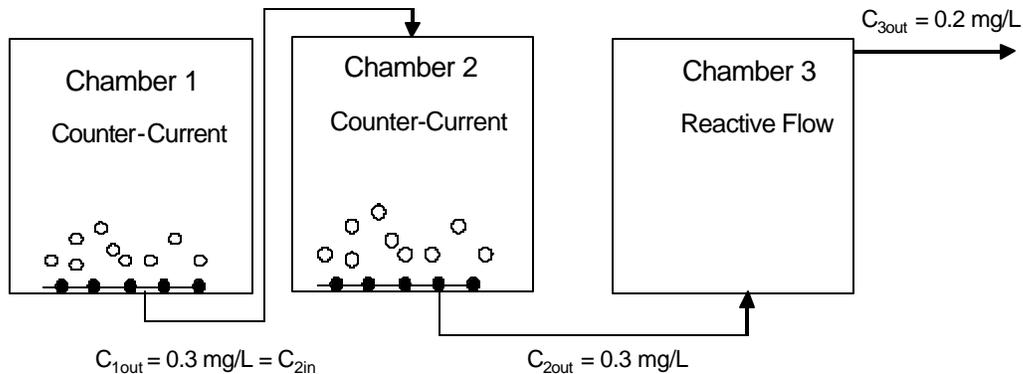
In order to apply Equation 11-1, both C and HDT must be known. These two parameters can be determined for individual chambers or for zones consisting of multiple, adjacent chambers. In general, if the concentration is measured at 3 or more points in the contactor the Extended-CSTR method will be used, so the CSTR method likely will not be applied when 3 or more zones (excluding the first dissolution chamber) are defined.

EPA recognizes that, for many situations, either the CSTR and T_{10} method can be used to calculate inactivation credit, and that they may generate two different estimates of log inactivation. EPA recommends that systems use, and States accept, the higher estimate of the log inactivation credit. However, systems should select one method to be used and use that method consistently.

Example - CT Calculation and Log Credit Determination using the CSTR Method with the concentration measured for each chamber

¹ k_{10} is calculated from the CT table with the following equation: Log inactivation = $k_{10} \times \text{CT}$

A system employs a three chamber ozone contactor, with ozone addition in the first two chambers. The second chamber is a counter-current flow dissolution chamber with influent and effluent ozone concentrations of $C_{in} = 0.3 \text{ mg/L}$ and $C_{out} = 0.3 \text{ mg/L}$. The effluent ozone concentration in the third, reactive chamber is $C_{out} = 0.2 \text{ mg/L}$. At 10° C , $k_{10} = 0.1005 \text{ L/mg-min}$. The HDT for each chamber = 20 minutes.



- 1) Determine the C values for each chamber

Chamber 1	No inactivation credit recommended
Chamber 2	$C = C_{out}/2 = 0.3 / 2 = 0.15 \text{ mg/L}$
Chamber 3	$C = C_{out} = 0.2 \text{ mg/L}$

- 2) Calculate the log inactivation for each chamber using Equation 11-1

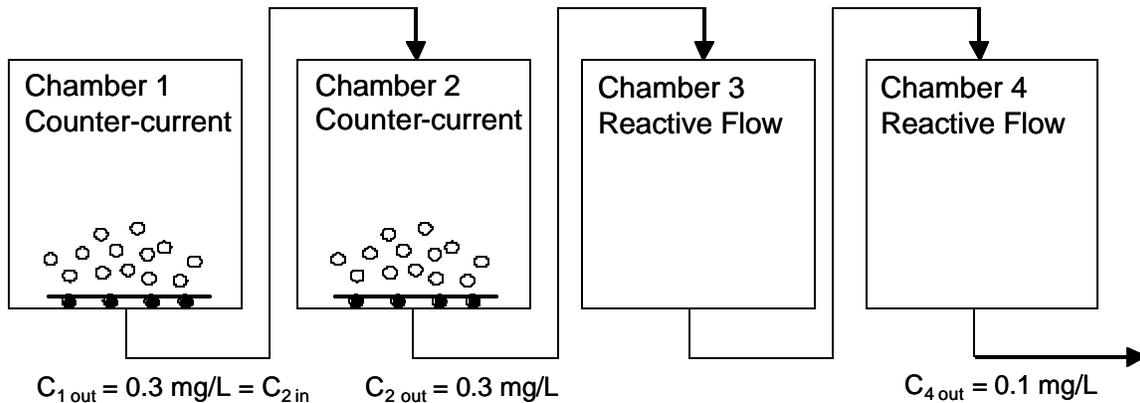
Chamber 2	$\text{Log inactivation} = \text{Log}(1 + 2.303 \times 0.1005 \times 0.15 \times 20) = 0.23$
Chamber 3	$\text{Log inactivation} = \text{Log}(1 + 2.303 \times 0.1005 \times 0.20 \times 20) = 0.28$

- 3) Sum the log inactivations to determine the log credit achieved.

The total log-inactivation across the contactor is $0.23 + 0.28 = 0.51$ log inactivation, therefore 0.5 log credit achieved.

Example - CT Calculation and Log Credit Determination using the CSTR Method with the concentration not measured for each chamber

A system employs a four chamber ozone contactor, with ozone addition in the first two chambers. The second chamber is a counter-current flow dissolution chamber with influent and effluent ozone concentrations of $C_{in} = 0.3 \text{ mg/L}$ and $C_{out} = 0.3 \text{ mg/L}$. The effluent ozone concentration in the third, reactive chamber is unknown, and in the fourth, reactive chamber is 0.1 mg/L . At 10° C , $k_{10} = 0.1005 \text{ L/mg-min}$. The HDT for each chamber = 20 minutes. Chambers 3 and 4 are considered one zone, and the effluent concentration of Chamber 3 is assumed to be equal to that of Chamber 4.



- 1) Determine the C values for each chamber

Chamber 1	No inactivation credit recommended
Chamber 2	$C = C_{2 \text{ out}}/2 = 0.3 / 2 = 0.15 \text{ mg/L}$
Chamber 3	$C = C_{4 \text{ out}} = 0.1 \text{ mg/L}$
Chamber 4	$C = C_{4 \text{ out}} = 0.1 \text{ mg/L}$

- 2) Calculate the log inactivation for each chamber using Equation 11-1

Chamber 2	$\text{Log inactivation} = \text{Log}(1 + 2.303 \times 0.1005 \times 0.15 \times 20) = 0.23$
Chamber 3	$\text{Log inactivation} = \text{Log}(1 + 2.303 \times 0.1005 \times 0.1 \times 20) = 0.17$
Chamber 4	$\text{Log inactivation} = \text{Log}(1 + 2.303 \times 0.1005 \times 0.1 \times 20) = 0.17$

- 3) Sum the log inactivations to determine the log credit achieved.

The total log-inactivation across the contactor is $0.23 + 0.17 + 0.17 = 0.57 \text{ log}$ inactivation, therefore 0.5 log credit achieved.

11.3.4 Extended CSTR Approach

The Extended CSTR approach requires the measurement of the ozone concentration at a minimum of three points within the contactor. These data are used to develop a predicted ozone concentration profile through the contactor. The Extended CSTR approach generally results in lower doses of ozone resulting in the same level of inactivation, when compared to the CSTR method. Appendix B provides a complete description of the Extended CSTR approach.

11.4 Monitoring Requirements

11.4.1 LT2ESWTR

The LT2ESWTR (40 CFR 141.730) requires **daily CT monitoring** conducted **during peak hourly flow** (40 CFR 141.729(a)). Since systems may not know when the peak hour flow will occur, EPA recommends monitoring on an hourly basis. Contact time does not have to be determined on a daily basis, only concentration. Systems should reevaluate contact time whenever they modify a process and the hydraulics are affected (e.g., add a pump for increased flow, reconfigure piping).

The concentration of ozone must be measured with the indigo colorimetric method, Standard Method 4500-O₃ B (40 CFR 141.729(a)). Details on these methods can be found in *Standard Methods for the Examination of Water and Wastewater*, 19th edition, American Public Health Association, 1995. Appendix C provides information on sample collection, preparation and stability of reagent, and calibration and maintenance of online monitors.

11.4.2 Stage 1 DBPR

The Stage 1 DBPR requires all systems using ozone for disinfection or oxidation to take at least one bromate sample per month for each treatment plant using ozone (See the Stage 1 DBPR, 40 CFR 141.132(b) for further information). Samples must be taken at the distribution system entry point when the ozone system is operating under normal conditions. Systems may reduce monitoring from monthly to quarterly if the system demonstrates that the annual average raw water bromide concentration is less than 0.05 mg/l, based on monthly measurements for one year. The MCL for bromate is 10 µg/l based on a running annual average.

11.5 Unfiltered System LT2ESWTR Requirements

The LT2ESWTR requires unfiltered systems to meet the following requirements (40 CFR 141.721(b) and (c)):

- Provide at least 2.0 log *Cryptosporidium* inactivation
- If their source water *Cryptosporidium* concentration is greater than 0.01 oocyst/liter then the system must provide 3.0 log *Cryptosporidium* inactivation
- Use a minimum of two disinfectants to meet overall disinfection requirements

The requirements of the previous SWTR regulations still apply— achieve 3 log inactivation of *Giardia* and 4 log inactivation of viruses, and maintain a disinfectant residual in the distribution system (e.g., free chlorine or chloramines).

The monitoring requirements described in section 11.4 apply to unfiltered systems. Additionally, unfiltered systems must meet the *Cryptosporidium* log-inactivation requirements every day the system serves water to the public, except one day per calendar month (40 CFR 141.721(c)). Therefore, if an unfiltered system fails to meet *Cryptosporidium* log-inactivation two days in a month, it is in violation of the treatment technique requirement.

11.6 Toolbox Selection

Selecting ozone disinfection to receive *Cryptosporidium* inactivation credit for compliance with the LT2ESWTR has cost, operational, and upstream and downstream process implications. The ozone CT requirements for *Cryptosporidium* inactivation are significantly higher than for *Giardia* and virus, and capital requirements could be substantial for a system seeking higher than 0.5 credit. As a result, ozone is likely a better option for systems that will benefit from its other treatment effects. This section discusses the potential advantages and disadvantages of ozone processes.

11.6.1 Advantages

Ozonation reduces many other contaminants and improves process performance, both directly and indirectly. The indirect benefits are those where other aspects of the treatment process can be improved or changed, resulting in a higher finished water quality. The advantages of ozone use include:

- Total organic carbon (TOC) reduction
- Iron, manganese, and sulfide oxidation

- Taste, odor, and color control
- Trihalomethane (THM) and haloacetic acid (HAA) reduction with reduction in chlorine use
- Biological stability with biological filtration

11.6.2 Disadvantages

Considering only benefits from *Cryptosporidium* inactivation credit, the capital, operational, and maintenance costs are relatively high compared to other toolbox options for similar credit, especially for systems treating colder water. Other disadvantages include:

- Higher level of maintenance and operator skill required.
- Additional safety and containment issues with ozone contactors.
- Possible need for three-phase power which may not be compatible with some water systems.
- Bromate formation (bromate is a regulated DBP).
- Upstream processes can cause fluctuations in ozone demand, thus affecting ozone residual control.
- Assimilable organic carbon (AOC) production, which can contribute to biofilm growth in the distribution system if not removed.
- High capital requirements to achieve CT requirements with low water temperatures (below 10 °C).

11.7 Disinfection With Ozone

11.7.1 Chemistry

Ozone decomposes spontaneously during water treatment by a complex mechanism that involves the generation of hydroxyl free radicals (Hoigné and Bader 1983a and 1983b; Glaze et al. 1987). The hydroxyl free radicals are among the most reactive oxidizing agents in water, with reaction rates on the order of $10^{10} - 10^{13} \text{ M}^{-1} \text{ s}^{-1}$ (Hoigné and Bader 1976). The half-life of hydroxyl free

radicals is on the order of microseconds. Concentrations of hydroxyl free radicals can never reach levels above 10^{-12} M (Glaze and Kang 1988).

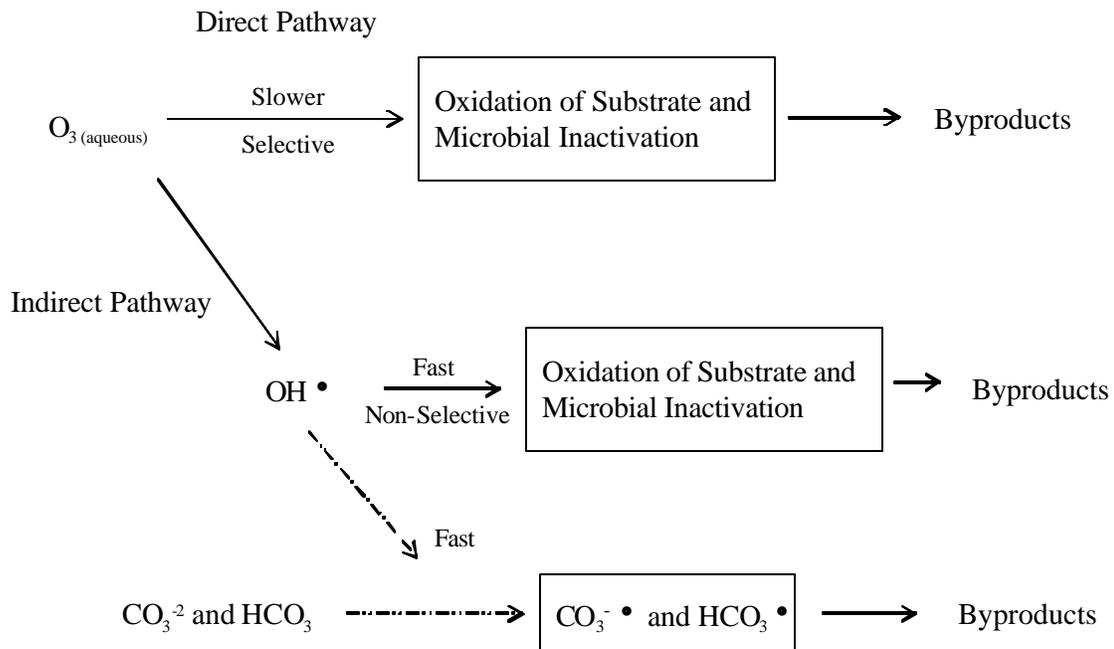
When ozone is added to water, it reacts through two possible pathways (see Figure 11.1):

- Direct oxidation of compounds by molecular ozone in the aqueous phase.
- Oxidation of compounds by hydroxyl free radicals produced during the decomposition of ozone.

As indicated in Figure 11.1, the direct reaction with molecular ozone is relatively slow compared to the hydroxyl reaction. However, the reaction with many aqueous species is still very rapid compared to other disinfectants. The reaction mechanisms for microbial inactivation are poorly understood, and there is conflicting research regarding the pathway more responsible for disinfection.

Park et al. (2001) researched the ozone reaction mechanisms using natural waters. The authors described the ozone consumption rate with two steps: an initial rapid consumption step (ozone consumed after a few seconds) followed by a slower ozone decay step. Results showed the ozone consumption in the initial rapid reactions increased with increasing ozone dose (for raw water only; sand filtered water showed no change) and increasing TOC levels. However, the slower decay reaction rates decreased with increasing ozone dose. Consequently, the decay reaction was slower at higher applied ozone doses. This is of importance for considerations to ozone dose requirements and residual maintenance.

Figure 11.1 Reaction Pathways of Ozone in Water



Direct oxidation is the dominant pathway at neutral pH and lower. While the direct pathway is minor in the initial reaction, it becomes more dominant in the slower decay stages. At higher pH levels, the formation of the hydroxyl radical is favored. Advanced oxidation processes induce conditions that favor the hydroxyl radical formation and increase the rate of ozone decomposition. (See Chapter 7 of the *Alternative Disinfectants Guidance Manual* for information on advanced oxidation processes).

11.7.2 Byproduct Formation

Reactions between ozone and natural organic matter (NOM) can form a variety of organic byproducts including aldehydes, ketones, and acids. Inorganic byproducts are also formed. Bromide reacts with ozone and hydroxyl radicals to form bromate, a regulated drinking water contaminant with an MCL of 10 $\mu\text{g/l}$. Brominated organic compounds can also be formed, such as bromoform and dibromoacetic acid, which are also regulated through the total trihalomethanes (TTHMs) and haloacetic acids (HAA5) MCLs under the Stage 2 DBPR.

11.7.2.1 Bromate and Brominated Organic Compounds

Bromate and brominated organic compound formation is dependent on water quality and treatment conditions, and only occurs in waters with bromide ion present. Bromate concentration

increases with increasing pH, carbonate alkalinity, bromide concentration, ozone dose, and temperature. However, attempts at reducing bromate formation by lowering pH may increase the formation of brominated organic byproducts. The source water bromide concentration is an important factor when considering adding ozone to a treatment process.

11.7.2.2 Non-Brominated Organic Compounds

Ozone reacts with NOM and breaks larger organic molecules down into simpler, more biodegradable compounds such as aldehydes, ketones, and acids. These biodegradable organic molecules are a food source for microorganisms and can affect biological growth in the distribution system. Escobar and Randall (2001) conducted a case study at a ground water treatment plant that was adding ozone to improve the aesthetic quality of the water. They found that the assimilable organic carbon (AOC; the fraction of total organic carbon that is most readily utilized by bacteria) concentrations significantly increased in the distribution system, however, with diligent maintenance of chlorine residual biological growth was suppressed. Biofilters can be used to reduce the AOC entering the distribution system. (Section 11.9.3 describes biofilters and their operation.)

11.8 Design

11.8.1 Generators and Contactors

There are several types of ozone generators and contactors. All generators use oxygen as a raw material and convert it to ozone using electrochemical reactions. They differ from each other in the source of oxygen used and the configuration of generator elements. Generators can use either air or pure oxygen as an oxygen source. The *Alternative Disinfectants and Oxidants Guidance Manual* describes the type of generators and contactors in detail.

11.8.2 Point of Addition

Raw water quality, turbidity, and ozone demand are commonly used to assess the possible locations for adding ozone. The *Alternative Disinfectants and Oxidants Guidance Manual* describes the water quality characteristics, advantages, and disadvantages of feed points at a raw water location, after sedimentation, and after first-stage filtration of a two-stage process. The general considerations are:

- Placing the ozone addition point further downstream ozone, particularly after physical removal processes, generally reduces both the ozone demand and byproduct formation.

- Adding ozone ahead of filtration allows any biodegradable organics, formed from the ozonation of more recalcitrant TOC, to be removed by subsequent biological activity in the filters. Also, solid-phase manganese and iron formed through oxidation by ozone can also be removed by the filters.

In general, applying ozone prior to coagulation can enhance clarification. Applying prior to filtration can also improve filtration performance; however these effects are site-specific and are likely to depend on ozone dose.

Detrimental impacts on filtration operation have also been reported. Bishop et al. (2001) investigated the effects of ozone on filtration with a raw water of moderate turbidity, TOC, iron, and manganese concentrations. With ozone doses of 0.5 to 1.0 mg/L, turbidity increased in the contactors with visible floc formation. At lower ozone doses, 0.16 to 0.35 mg/L, the turbidity still increased, but not as much as the higher ozone dose. Because of the higher filter loadings, the duration of filter cycles decreased. The authors believed the increased turbidity was partially due to solid-phase manganese formation, and also likely due to the organic matter and residual metals.

11.8.3 Biologically Active Filters

When ozone oxidizes organic matter, the AOC in the water typically increases. Some systems use biologically active filters to remove the AOC prior to chlorination and entry to the distribution system. Microbes present in the upper portion of the filters consume the AOC, mineralizing them to carbon dioxide and water, and reducing the amount available to microorganisms in the distribution system (e.g. microorganisms in pipeline biofilm) and for DBP formation.

11.8.3.1 Media for Biologically Active Filters

Any filter media which has sufficient surface area for microbes to attach to can be used for biological filtration. Slow sand, rapid sand, and GAC filters have all been successfully used for biologically active filtration. Research indicates that both sand/anthracite and sand/GAC filters can support the total amount of biomass to sufficiently remove organic components (LeChevallier et al. 1992; Krasner et al. 1993; Coffey et al. 1995). Wang and Summers (1996) and Zhang and Huck (1996) have shown that the contact time with the biofilm is more important than the mass of biofilm above a minimum level of biomass. Generally, the longer the contact time the greater the removal of AOC. However, the increase in removal is not a linear-relationship; the removal rate decreases at extended contact times (Zhang & Huck 1996). DBP precursors most often take longer to biodegrade making extended contact times necessary if this is the process goal. This can be achieved with deep anthracite filter beds or GAC filters (Prevost et al. 1990). The adsorption capacity of GAC provides a longer time for the organic compounds to be consumed by the biomass as the particles are adsorbed by the GAC (LeChevallier et al. 1992).

11.8.3.2 Operating Biologically Active Filters

It is not necessary to seed a biological filter in order to obtain the necessary biological growth. The organisms naturally present in the system are sufficient to obtain the needed growth. The only additional requirement is to provide the conditions for biological growth. These conditions include necessary food sources, sufficient dissolved oxygen, nutrients, proper pH and temperature. The products from ozone and NOM reactions will provide the needed food for the microorganisms to grow. The reaction of ozone also produces oxygen as one of its products, so the dissolved oxygen concentration should be sufficiently high. Generally the pH and nutrient levels in most waters will also be sufficient to allow the necessary growth. Organic removal will generally be higher at higher temperatures. Several studies have found significantly decreased removal at temperatures below 15 degrees Celsius (Krasner et al. 1993; Coffey et al. 1995; Daniel and Teefy 1995).

In order to maintain biological growth, a disinfectant other than ozone cannot be added prior to the filters. GAC filters can reduce small disinfectant residuals through reaction with the carbon, however, this can lead to physical breakdown of the GAC and more frequent media replacement. Using chlorinated or chloraminated backwash water can also be a concern. Studies have shown mixed results with chlorinated backwash water, with some showing no effect and others showing significantly reduced removal (Miltner et al. 1996; Miltner et al. 1995; Hacker et al. 1994; Reckhow et al. 1992; McGuire et al. 1991). Short vigorous backwashes with a relatively low chlorine dose may be more effective in maintaining biological filtration than less vigorous backwashes at longer times with higher chlorine doses (Urfer et al. 1997).

11.9 Safety Considerations in Design

Ozone is a corrosive gas and according to Occupational Safety and Health Administration (OSHA) Standards, exposure to airborne concentrations should not exceed 0.1 mg/L (by volume) averaged over an eight-hour work shift.

Ozone generators should be housed indoors for protection from the environment, and to protect personnel from leaking ozone in the case of a malfunction. Ventilation should be provided to prevent excess temperature rise in the generator room, and to exhaust the room in the case of a leak. Adequate space should be provided to remove the tubes from the generator shell and to service the generator power supplies. Off-gas destruct units can be located outside if the climate is not too extreme. If placed inside, an ambient ozone detector should be provided in the enclosure. All rooms should be properly ventilated, heated, and cooled to match the equipment-operating environment.

11.10 Operational Issues

When using ozone for disinfection, it is important to evaluate all the factors that could affect the CT achieved. For example, if raw water quality fluctuates and ozone demand increases, without adjusting the ozone dose, the residual concentrations will decrease. The system is now at risk of not achieving the required level of CT. The ozone demand, pH, and temperature of the raw water, under worst-case to best-case conditions, should be evaluated to determine their effect on ozone disinfection. Systems should develop standard operating procedures (SOPs) for addressing changes in raw water quality. The remainder of this section discusses the how these factors affect ozone disinfection and the CT calculation.

11.10.1 Ozone Demand

The following water quality constituents contribute to ozone demand:

- Natural organic matter (NOM)—Ozone will oxidize organic matter, which includes compounds causing taste and odor. As discussed in section 11.8.2 organic byproducts are also produced.
- Synthetic organic compounds (SOCs)—Some SOCs can be oxidized and mineralized under favorable conditions.
- Bromide—Ozone will oxidize bromide forming, hypobromous acid, hypobromite ion, bromate ion, brominated organics, and bromamines.
- Bicarbonate or carbonate ions—The hydroxyl radical reacts with bicarbonate and carbonate ions and form carbonate radicals.

Ozone demand is particularly important to the CT calculation since it directly affects the residual ozone used in the CT calculation. Ozone concentrations in water are generally monitored continuously using an aqueous ozone residual monitor, and confirmed periodically using the batch indigo method. As the ozone demand changes, the amount of ozone applied can be adjusted to maintain the desired CT.

11.10.2 pH

The pH of water does not have a significant effect on ozone disinfection capabilities. However, there is strong impact of pH on ozone demand and decay rate. As pH increases, the hydroxyl radical decomposition pathway is favored and the initial demand and rate of decay increase substantially.

11.10.3 Temperature

The CT requirements are based on temperature; as temperature decreases, the CT required to achieve a given level of inactivation increases. Conversely, the rate of ozone decay decreases as temperature decreases, generally resulting in a higher CT for a given ozone dose. The ozone process should be designed to provide the necessary log inactivation under all conditions. Standard operating procedures (SOPs) should also describe process adjustments required to operate at the lowest water temperatures experienced by the system in the past 10 years.

11.10.4 Maintaining Residual Disinfectant in the Distribution System

It is necessary to maintain a residual in the distribution system to prevent microbial regrowth. Because of the reactive nature of ozone, its residual tends to dissipate within minutes and cannot be relied upon to maintain a disinfectant throughout the distribution system. Therefore, a secondary disinfectant must be used, usually either chlorine or chloramines.

11.11 Request for Comment on Segregated Flow Analysis

As mentioned in section 11.3, EPA is evaluating the segregated flow analysis (SFA) to estimate CT for ozone disinfection. The SFA approach is based on an assumption that the residence time distribution (RTD) of an ozone contactor is sufficient to completely describe the hydrodynamics within the contactor (i.e., zero micro-mixing occurs). If micro-mixing does occur, then the SFA approach may overestimate the inactivation of microorganisms. The degree to which inactivation may be overestimated depends on several factors including the predicted ozone decay, the predicted inactivation, and the extent that the hydrodynamics within the contactor deviate from ideal plug-flow conditions (as indicated by the RTD).

Incorporating micro-mixing calculations into the SFA is quite complicated, and likely impractical for many systems. EPA requests comments on the SFA approach and the following questions:

1. Should the impact of micro-mixing be considered?
2. Can a worst case scenario, incorporating reactor configuration, reaction kinetics and complete micro-mixing be developed?
3. Can appropriate safety factors be established to ensure the SFA approach does not overestimate inactivation?

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12.0 Demonstration of Performance (DOP): Microbial Removal

12.1 Introduction

The purpose of the “demonstration of performance” (DOP) toolbox component is to allow a system to demonstrate that a plant, or a unit process¹ within a plant, should receive a higher *Cryptosporidium* treatment credit than is presumptively awarded under the LT2ESWTR. Presumptive treatment credits are applicable to granular media filtration plant types indicated in Table 12.1 that comply with the provisions of the Interim Enhanced Surface Water Treatment Rule (IESWTR) and Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR) (40 CFR 141.720). These credits are also applicable to unit processes in the microbial toolbox when they meet specified design and operational criteria, as discussed in other chapters of this manual.

Table 12.1 Filtration Plant Types Eligible for DOP

Plant Type	Minimum Elements of Process Train
Conventional	Coagulation/Flocculation Sedimentation High Rate Granular Media Filtration
Slow Sand Filtration	Slow Sand Filtration
Diatomaceous Earth	Diatomaceous Earth Filtration
Softening/Granular Media Filtration	Single-Stage Lime Softening High Rate Granular Media Filtration
Direct Filtration	Coagulation/Flocculation High Rate Granular Media Filtration

Where a system can demonstrate that a plant, or a unit process within a plant, consistently achieves a *Cryptosporidium* treatment efficiency greater than the presumptive credit specified in the LT2ESWTR, the State may allow the system to receive a higher *Cryptosporidium* treatment credit for compliance with the LT2ESWTR (40 CFR 141.727(c)). To demonstrate the higher level of *Cryptosporidium* treatment, systems should conduct a site-specific study using a protocol approved by the State. This study should account for all expected operating conditions and, at the discretion of the

¹EPA requests comment on how a system would conduct a DOP of a unit process while ensuring the other parts of the treatment process were achieving their assumed *Cryptosporidium* treatment. For example, maximizing removal in a pre-sedimentation basin can cause reduced removal in the subsequent sedimentation basin and filters.

State, determine ongoing monitoring and/or performance requirements to ensure conditions under which the DOP was awarded are maintained during routine operations.

In general, the term “treatment” in the LT2ESWTR refers to both physical removal and inactivation of *Cryptosporidium*. Treatment credits discussed in this chapter pertain to physical removal by the process trains listed in Table 12.1 (or individual components of these trains), pre-sedimentation, bank filtration, secondary filtration, and two-stage softening. Treatment credits for physical removal by membranes and bag and cartridge filtration are addressed in the *Membrane Filtration Guidance Manual* and Chapter 8 of this manual, respectively. Inactivation of *Cryptosporidium* by chlorine dioxide, ozone, and UV may also be used to provide additional treatment credits, as discussed in Chapters 10, 11, and 13 of this manual.

This chapter provides guidance for implementing the DOP toolbox option and is organized as follows:

- 12.2 LT2ESWTR Compliance Requirements - discusses DOP treatment credit with respect to other toolbox options and reporting requirements.
- 12.3 Toolbox Selection Considerations - describes selection considerations for plants to consider before conducting a DOP study, the duration of a DOP study, and an approach for conducting a DOP study.
- 12.4 DOP Criteria Development - discusses key issues of DOP design including process evaluation criteria, selection of performance indicators, and full-scale versus pilot-scale testing.
- 12.5 Demonstration Protocol - discusses the minimum elements that should be included in the DOP protocol - DOP test matrix, DOP monitoring plan, DOP implementation, and data analysis and reporting.

12.2 LT2ESWTR Compliance Requirements

12.2.1 Credits

The LT2ESWTR does not specify how treatment performance must be demonstrated; however the protocol used must be approved by the State (40 CFR 141.727(c)). Determination of an increased *Cryptosporidium* treatment credit will be made by the State.

The LT2ESWTR **does not allow** systems to claim presumptive credit for the toolbox options listed below, if that component is included in the DOP credit (40 CFR 141.727(c)(2)).

- Presedimentation
- Two-stage lime softening
- Bank filtration
- Combined or individual filter performance
- Membrane filters
- Bag and cartridge filters
- Second stage filtration

For example, if a plant receives a DOP credit for a treatment train, the system may not also receive credit for a presedimentation basin or achieving the lower finished water turbidity of the combined filter performance option.

States may award a lower level of *Cryptosporidium* treatment credit towards compliance for the LT2ESWTR to a system where, based on site-specific information, a plant or a unit process achieves a *Cryptosporidium* treatment efficiency less than a presumptive credit specified in the LT2ESWTR (40 CFR 141.727(c)(1)).

12.2.2 Reporting Requirements

The LT2ESWTR requires results from the testing be submitted no later than [date 72 months after promulgation] for large systems and [date 102 months after promulgation] for small systems (40 CFR 141.730).

The State may require systems to report operational data on a monthly basis to verify that conditions under which DOP credit was awarded are maintained during routine operation (40 CFR 141.730).

12.3 Toolbox Selection Considerations

The DOP toolbox option is intended for plants that operate at a high level of performance. A system should review existing performance data to verify that it can meet high performance levels under a range of operating conditions (including filters out of service, returning to service, and flow rate changes) before conducting a DOP study. EPA recommends systems achieve less than 0.1 NTU in each individual filter effluent as an indicator for considering whether the DOP option is practical.

Before applying the DOP approach to an individual unit process, facilities should carefully consider the potential advantages and disadvantages of such an approach. The microbial toolbox allows for treatment credits for unit processes based on specified design and/or operational criteria described in other chapters of this manual. It is possible that a detailed DOP program may result in a lower credit than already granted by the LT2ESWTR.

A DOP study should be conducted for a minimum of one year. Systems should have a contingency plan for achieving compliance with the LT2ESWTR if the DOP does not provide the anticipated credit.

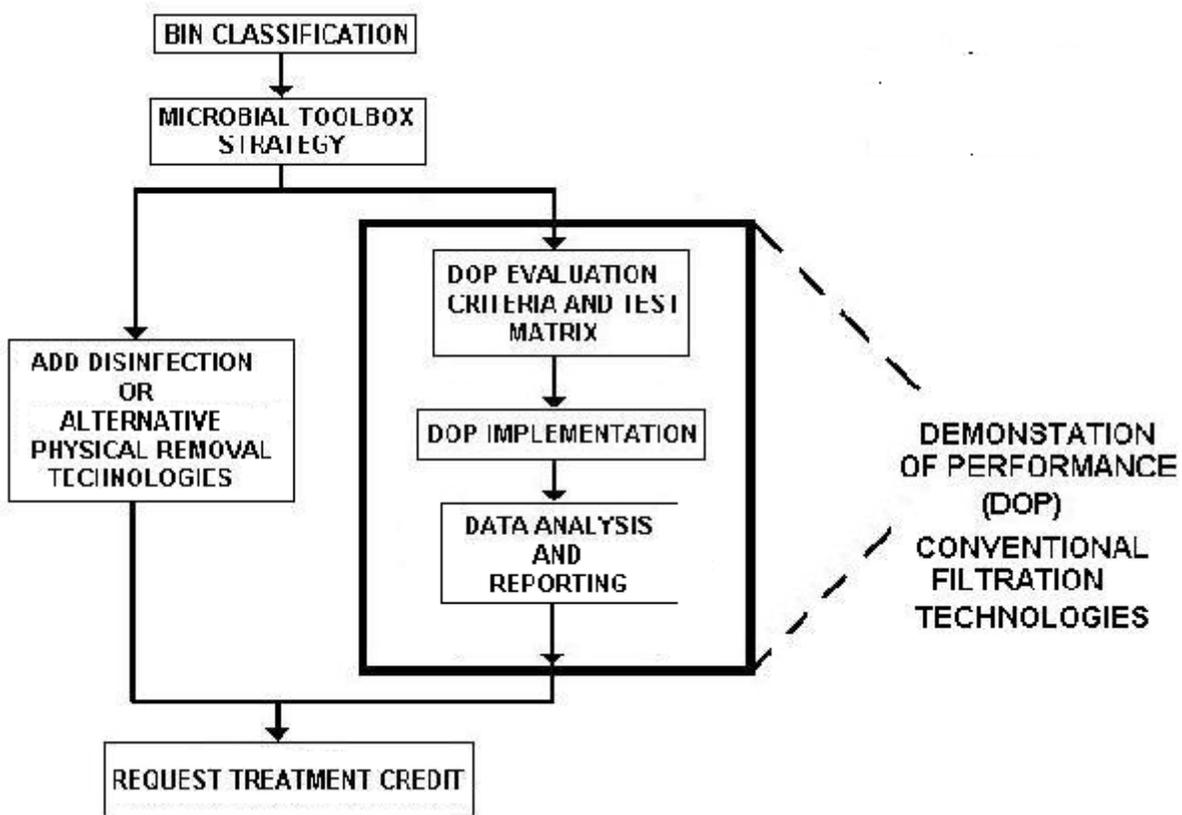
12.3.1 Overview of the Demonstration Protocol

This chapter presents one approach for conducting a DOP study. Other approaches or modifications to this approach may be approved by the State. Major elements of the DOP protocol include the following:

- Development of DOP evaluation criteria and test matrix
- DOP implementation
- Data analysis and reporting

Figure 12.1 presents a flowchart relating these elements to the overall microbial toolbox framework. Each of these topics is discussed in detail in this chapter.

Figure 12.1 Flowchart for DOP Protocol



12.4 DOP Criteria Development

Source water *Cryptosporidium* levels and water quality characteristics vary from system to system. Accordingly, DOP programs should be tailored to address site-specific process issues associated with each water treatment plant (WTP). Major questions that should be resolved during the design of the DOP include (but are not limited to) the following:

- What are the governing process evaluation criteria and treatment objectives?
- What microorganism or surrogate parameter(s) should be used to demonstrate removal efficiency of *Cryptosporidium*?
- Should the DOP be conducted at full-scale or pilot-scale?

Each of these questions is addressed in the following sections.

12.4.1 Process Evaluation Criteria

Process evaluation encompasses the treatment objectives of the plant, influent water quality, system demand, and operating conditions or treatment techniques. The DOP plan should address all critical operating conditions, whether conducted in full-scale or pilot-scale. Influent water quality, flow rates, process configurations, and operating conditions need to be clearly defined during the development of the DOP plan. Common process evaluation criteria are discussed in this section.

12.4.1.1 Treatment Objectives

The DOP toolbox option primarily relates to *Cryptosporidium* removal by physical methods such as clarification and filtration. However, WTPs are tasked to remove or control multiple contaminants in the source water besides *Cryptosporidium*. The impact of operational strategies and treatment methods for other contaminants on the efficiency of *Cryptosporidium* removal should be considered during the DOP criteria development stage. The system should not change its operational strategy between the DOP study conditions and routine operation after the study has ended—the DOP credit is based on the operational strategy used in the study. For example, a system that uses enhanced coagulation throughout the study period should also use it during routine operation for compliance with the LT2ESWTR.

Other examples of treatment techniques that can affect *Cryptosporidium* removal and thus should be considered in the development stage include the following:

- Prechlorination may be used to enhance floc formation (and *Cryptosporidium* removal) in filtration trains. However, prechlorination may also promote trihalomethane (THM) and haloacetic acid (HAA) formation. Therefore, prechlorination doses used during the DOP study should be set to balance floc and disinfection byproduct formation. Operational guidelines should be documented in the DOP plan.
- Granular media filter run times may be extended to increase unit filter run volumes (UFRVs) and filter efficiency. However, increased UFRVs also increase the potential for *Cryptosporidium* breakthrough. Maximum UFRVs should be established to minimize *Cryptosporidium* breakthrough.
- Alternative coagulation strategies may be used to enhance *Cryptosporidium* removal in granular media filters but may also result in post-filtration flocculation that can cause deposition or scaling in water distribution systems. Coagulant dosing rates should be set during the DOP study to minimize downstream floc formation.

Additionally, if a treatment process or plant technique is used intermittently for a seasonal or sporadically occurring contaminant, this treatment should also be used as needed during the DOP study, consistent with routine operation.

12.4.1.2 Influent Water Quality Characteristics

Source water quality characteristics that may affect *Cryptosporidium* removal efficiencies should be identified. These will depend on the treatment processes employed and may include (but are not limited to) turbidity, pH, alkalinity and temperature. Critical (or worst-case) ranges for these parameters that are anticipated over the plant design life or permit period should be clearly defined. The demonstration study should include tests run under the worst-case source water conditions. In pilot-scale DOP studies, raw source water can be modified to simulate worst-case water qualities.

12.4.1.3 System Flow Rate

The system flow rate or range of flow rates to be evaluated during the DOP should be clearly defined. Where possible, plant performance should be demonstrated for the critical flow condition that defines permitted plant capacity (e.g., peak instantaneous flow or peak daily flow). For full-scale studies, this may not be feasible for facilities that operate significantly below permitted or maximum capacity. For pilot-scale studies, the range of system unit process flow rates should replicate the full-scale low, intermediate, and maximum flow and recycles rates.

12.4.1.4 Plant Operating Conditions

WTP operations can vary significantly over the course of the demonstration period due to various factors including, but not limited to, raw water quality, system flow rate, and maintenance activities. The critical operating conditions that may impact *Cryptosporidium* removal at the WTP should be defined. Issues to consider include the following:

- What are the normal and worst-case operating conditions for each unit process with respect to *Cryptosporidium* removal?
- How many process trains or elements are normally in service? How will the plant perform when units are out of service for maintenance and repair, thereby increasing unit process flow rates (particularly in filters)?
- What is the process control strategy for chemical addition? How does this relate to *Cryptosporidium* removal?

- What is the process control strategy for filter operations? How does this relate to *Cryptosporidium* removal?
- How will the plant's recycle, backwash, and filter-to-waste schemes affect *Cryptosporidium* removal?

In the case of pilot-scale studies, performance demonstrations should replicate full-scale operating conditions in any respect that may influence *Cryptosporidium* removal.

12.4.2 Selection of Performance Indicators

Although the LT2ESWTR mandates treatment controls for *Cryptosporidium*, it is not currently feasible to demonstrate actual *Cryptosporidium* removal at full-scale facilities. In most cases, influent *Cryptosporidium* levels are not consistently high enough to demonstrate significant (such as 4 log) removal across the process train. Raw water spiking of *Cryptosporidium* is not a feasible option at full-scale facilities due to the potential health risk to system users and the number of oocysts required. Consequently, alternative indicators of *Cryptosporidium* removal will be needed for facilities that plan to conduct DOP studies at full-scale.

12.4.2.1 Surrogate Parameters for *Cryptosporidium*

EPA has reviewed a number of studies that suggest aerobic bacteria spores are a suitable indicator of *Cryptosporidium* removal in conventional treatment trains (coagulation, flocculation, sedimentation and filtration). Some characteristics of aerobic spores (as summarized by Cornwell et al., 2001) are:

- Naturally occurring (Nieminski and Bellamy 2000, Jakubowski et al. 1996).
- Do not pose health risks (Jakubowski et al. 1996, Rice et al. 1996).
- Can be detected at low concentrations (< 1 cfu/100 mL).
- Are slightly smaller than *Cryptosporidium* oocysts (Rice et al., 1996).
- Spore removal by water treatment is a conservative indicator of *Cryptosporidium* removal (Rice et al. 1996, Dugan et al. 1999, Nieminski and Bellamy 2000, Emelko 2001).
- Reduction of indigenous spores by inactivation is expected to be negligible in comparison with removal of spores by physical processes (Jakubowski et al. 1996, Rice et al. 1996).

- Aerobic spores do not undergo re-growth during treatment.

Although aerobic spores appear to be a suitable indicator for *Cryptosporidium* removal in filtration plants, raw source water spore concentrations will likely not be high enough throughout the study period to demonstrate high log removal across a full-scale treatment train.

The State may accept alternative indicators for *Cryptosporidium*; however, they should not be more easily removed than *Cryptosporidium*. The surrogate parameter should give a direct view of removal and should be an element that is not created in the plant (e.g., particle counts caused by chemical precipitation). Furthermore, the method of measurement should be sensitive enough to detect temporal variations in the parameter. Parameters such as turbidity or particle counts may be used in the DOP study, but are not suitable as stand-alone surrogates.

12.4.2.2 Long-Term Performance Indicators

As discussed previously, plants that implement a DOP plan should document long-term performance of filtration facilities for turbidity and/or particle count reduction. While turbidity and particle counts are not suitable as stand-alone indicators for full-scale *Cryptosporidium* removal, such data can be used to identify changes in the filtration performance.

It is recommended that individual filter efficiency be monitored frequently to identify differences in individual filter performance. This will allow the plant to assess temporal variations in filter effluent quality and will provide improved process control.

12.4.3 Full-Scale Versus Pilot-Scale Testing

In general, full-scale testing is preferred over pilot-scale testing since the performance of existing process trains is demonstrated directly. However, full-scale studies may not be feasible for many facilities for the following reasons:

- Influent *Cryptosporidium* levels will not be high enough to demonstrate high log removal. Likewise, influent aerobic spore concentrations may not be high enough to demonstrate significant log removal.
- Full-scale spiking with aerobic spores may not be feasible due to larger flows.
- Facilities may operate well below design or permitted flow capacity for the entire study period.

- Demonstration of worst-case operating conditions at full-scale may be difficult to plan, especially with regard to raw water quality and flow rates.

The major concern with the use of pilot-scale testing is the uncertainty associated with scale-up of pilot results to predict the performance of full-scale systems. Other potential limitations of pilot-scale studies are:

- Pilot-scale data generally represent steady-state conditions; however, sudden changes in flow or water quality may have a significant effect on *Cryptosporidium* removal; such changes are difficult to capture in a pilot-scale plant.
- Pilot-scale plants generally have much tighter process controls and higher levels of attention than full-scale plants; and thus, may not be indicative of actual full-scale performance.
- A pilot-scale plant cannot represent expected individual differences between multiple filters in a full-scale plant.
- Particle loadings to the treatment process in a pilot-scale study may be much higher than actual full-scale loadings, and thus, may not represent actual operating conditions.
- It may be too difficult to construct a pilot plant that represents the entire full-scale process train.

Pilot system dimensions and flow rates should be sufficiently large to minimize scale-up issues. Some recommended guidelines for pilot filter sizing include the following (USEPA 1991):

- Unit filtration rate in the pilot system should be identical to that of the full-scale plant.
- Pilot filter diameter should be greater than or equal to 100 times the media diameter.
- Media diameter and depth should be identical to that of the full-scale system.

Pilot systems should also incorporate all major process elements of the full-scale process train, including chemical addition systems and recycle streams. Such systems must be able to simulate flow rate and water quality perturbations (i.e., temporal disturbances to steady state conditions).

12.5 Demonstration Protocol

Once the DOP criteria have been developed, the DOP protocol can be formulated. This section outlines the minimum elements that should be included in the DOP protocol. Participation from the governing regulatory agency should be solicited during the DOP protocol development phase.

12.5.1 DOP Test Matrix

The first step in the formulation of the specific DOP protocol is the development of a matrix of test conditions to be evaluated during the DOP period. These test conditions should be formulated to assess *Cryptosporidium* removal (or other suitable parameters) under a range of normal and worst-case scenarios. The DOP matrix should clearly define specific test scenarios to be evaluated, incorporating the following criteria:

- Source water quality ranges– including minimum/maximum limits for critical water quality parameters that influence *Cryptosporidium* removal in the plant.
- Influent flow rates– including the maximum flow rate that defines plant capacity.
- Operating scenarios– including all operations that may cause process upset in the treatment train (e.g., events that cause temporal changes in water quality, and flow loadings to process units). These operations include, but are not limited to: filter backwashing, filter-to-waste practices, intermittent recycles, returning filters to service, and routine maintenance practices.

Critical influent flow ranges and operating conditions should be identified during the DOP criteria development phase, as described in section 12.2. The demonstration period should be at least one year, and should encompass all critical operating conditions. An example test matrix format is presented in Table 12.2.

Table 12.2 Example DOP Test Matrix

Scenario	Condition (Normal or Worst-Case)	Influent Concentration Range		Flow Rate Range	Units in Service	Backwash Conditions	Date of Scenario Test
		Surrogate	Turbidity				
S1	Normal	Average	Average	Average	4 (All)		
S2	Normal	Average	Average	Average	3		
S3	Worst Case A	Average	Average	High	3		
S4	Worst Case B	High	High	Average	3		
S5	Worst Case C	Low	Low	Average	3		

12.5.2 DOP Monitoring Plan

The DOP involves sampling and analysis of *Cryptosporidium* indicators in the raw source water and filtration train effluent over the course of a demonstration period defined by the DOP test matrix. Once the test matrix is established, the DOP monitoring plan should be formulated to define the following protocol details:

- Monitoring locations
- Test parameters (field and laboratory)
- Monitoring frequency
- Quality assurance/quality control (QA/QC) procedure for/during sampling

A sample DOP monitoring plan is presented in Table 12.3.

Table 12.3 Example DOP Monitoring Plan

Monitor Event Number	Date	Test Scenario ID (see Table 12.2)	Effluent Sample Locations ^A				Number of Samples per Location			
			Filter 1	Filter 2	Filter 3	Filter 4	Crypto/ Aerobic Spores	Particle Count	pH	Temp.
1	Week 1	S1	X	X	X	X	2 ^B	1	1	1
2	Week 2	S3	X		X	X	1	1	1	1
3	Week 3	S2	X	X	X		1	1	1	1
...
52	Week 52	S4	X	X	X	X	2 ^B	1	1	1

^A - Influent sample location identical for all test scenarios
^B - duplicate samples

12.5.2.1 Sampling Location

Paired samples should be collected from the plant influent (raw source) and the combined filter effluent for a DOP study of an entire plant. The plant influent location should be before the pre-sedimentation basins and off-stream storage facilities and follow any process recycles added prior to the first major unit process element of the treatment train. For pilot studies involving microbial dosing, the influent monitoring point should follow complete mixing of the source water and injection stream. The plant effluent sample should be comprised of composite samples from the effluent of all operating filters. It is recommended that at least five sample pairs (influent/effluent) be collected during each test run to capture temporal changes in filter and effluent quality.

12.5.2.2 Monitoring Parameters

Samples should be analyzed for all parameters required to assess *Cryptosporidium* removal in the treatment trains, as discussed in section 12.2. Parameters such as pH, alkalinity, temperature, and turbidity should be measured and recorded in the field.

12.5.2.3 Monitoring Frequency

A monitoring event is defined as a paired (concurrent) sampling of plant influent and filter effluent samples. At a minimum, monitoring should be performed once per week for 52 consecutive weeks. More frequent monitoring may be required to capture all critical operating scenarios defined by the DOP Test Matrix. The DOP database should be sufficiently large to allow for statistical analysis.

If a DOP credit is issued by the State, the credit will be conditional on continuing demonstration of a higher level of performance. The DOP Monitoring Plan can be modified to document continuing performance at a reduced sampling frequency. However, sampling events should still capture critical operating scenarios.

12.5.2.4 Quality Assurance/Quality Control

Quality assurance/quality control (QA/QC) sampling should be performed to allow assessment of data variability and quantification errors due to sample collection procedures and analytical methods. At a minimum, duplicate samples should be collected during one monitoring event per month.

12.5.3 DOP Implementation

The DOP should commence only after the State approves the DOP test matrix and monitoring protocol. The DOP plan should be administered by a qualified water treatment plant operator or water process engineer. Data review and QA/QC practices should be conducted routinely to ensure that the

objectives of the DOP program are met. Particular attention should be given to verification of the plant operating conditions (influent loadings, unit process loadings, etc.) to confirm that all critical operating scenarios identified in the DOP test matrix are evaluated during the demonstration period.

Personnel responsible for implementing the DOP monitoring plan should be properly trained in sample collection techniques, QA/QC procedures and operational data acquisition. Specific procedures should be used to collect and analyze samples as described in the following sections:

- Sample collection and preservation methods
- Analytical methods
- Microbial dosing methods (for pilot tests)
- Documentation procedures

12.5.3.1 Sample Collection Methods

Influent and effluent samples should be collected in a manner that is representative of the entire cross sectional flow at each monitoring point. If possible, monitoring points should be located in straight sections of pipe or channel well downstream of bends. For open channel flows, samples should be collected from mid-depth and mid-width of the channel. For pipe flow, samples should be collected from the tap directly into the sample containers. In each case, the sampling method should not reduce or prevent transfer of suspended solids from the process stream to the sample container. Parameters such as pH, turbidity, alkalinity and temperature should be directly measured in the field.

All samples should be grab samples. The individual effluent grab samples should not be combined to make up composite samples.

12.5.3.2 Analytical Methods

The analytical methods for monitoring *Cryptosporidium* under the LT2ESWTR are prescribed in the *Public Water System Guidance Manual for Source Water Monitoring under the Long-Term 2 Enhanced Surface Water Treatment Rule*. Analytical methods for all other water quality parameters should be performed in accordance with *Standard Methods for the Examination of Water and Wastewater*, 20th edition, or the most recent edition.

12.5.3.3 Microbial Dosing

For pilot testing that involves spiking of *Cryptosporidium*, aerobic spores or other indicators, microbial dosing procedures should be clearly established. Guidelines for microbial stock preparation and dosing are presented in this section.

A concentrated mixture of microorganisms should be prepared and fed to the raw source stream at a known feed rate, based on the microbial density in the concentrated stock, the flow rate of the pilot system, and the desired microorganism concentration in the pilot system. An equation that describes this relationship is:

$$Q_{\text{feed}} = \left(\frac{C_{\text{pilot}}}{C_{\text{feed}} - C_{\text{pilot}}} \right) Q_{\text{pilot}} \quad \text{Equation 12.1}$$

where:

- C_{pilot} = the microbial concentration in the pilot system
- C_{feed} = the microbial concentration in the concentrated stock solution
- Q_{pilot} = the flow rate of the pilot system (includes all process recycles present at the influent feed point, if applicable)
- Q_{feed} = the flow rate of the concentrated stock solution

For each trial, the test microorganisms should be completely mixed in a volume of raw water sufficient to supply the pilot plant for the duration of the experiment. The tank containing the suspension of test microorganisms should be continuously mixed for the duration of each experiment to promote homogeneity of the mixture. The concentrated stock should be delivered by a positive displacement pump (e.g., peristaltic) to the main process flow at a flow rate dictated by Equation 12.1. C_{pilot} and C_{feed} should be selected to provide a high enough influent microbial concentration to demonstrate at least 4 log removal in the pilot system. Based on this approach, C_{pilot} should be set at least 10^4 higher than the method detection limit for the test microorganism. The microbial density in the stock solution should be sampled at least twice, and preferably three times, during a feeding interval to verify consistent densities.

12.5.3.4 Documentation of WTP Operating Conditions

It is important to document WTP operating conditions during monitoring events to evaluate the effect of varying operating scenarios on *Cryptosporidium* removal. Standardized reporting forms should be developed to provide, at a minimum, the following information:

- System flow rate (instantaneous/flow chart, hourly and daily average)
- Operating mode (process scheme, number of trains, number of units in service)

- Water pH, alkalinity, turbidity and temperature
- Performance data
- Chemical addition rates/doses
- Mechanical equipment in operation, with flow rates (major pumps, blowers, etc.)
- Recycle and backwash flows/rates
- Related maintenance activities occurring prior to or during sampling event.

12.5.4 Data Analysis and Reporting

12.5.4.1 Evaluation of Performance

To receive DOP treatment credits above presumptive credits in the LT2ESWTR, a plant should demonstrate consistent attainment of a specific log reduction of *Cryptosporidium* (or suitable indicators). To meet this objective, log reduction should first be computed for each monitoring event according to:

$$\text{Log Removal} = -\log (C_{\text{inf}}/C_{\text{eff}}) \quad \text{Equation 12.2}$$

where: C_{inf} = influent *Cryptosporidium* or indicator concentration
 C_{eff} = effluent *Cryptosporidium* or indicator concentration

For effluent samples in which no *Cryptosporidium*, spores, or other indicators are detected, the concentration should be set to the method detection limit.

The State will determine the level of DOP credit a facility receives based on review of the log removal data.

For the case of pilot testing and the use of multiple indicators for *Cryptosporidium* removal calculations will be site specific.

12.5.4.2 Reporting for the DOP

At the conclusion of the DOP test period, a detailed report summarizing the major findings of the DOP program must be submitted to the governing regulatory agency. At a minimum, the DOP report should include the following information:

- Detailed description of full-scale WTP, including process flow schematics
- Summary of treatment objectives and WTP design criteria
- DOP test matrix and monitoring plan
- DOP data summary
- Detailed pilot plant design data (if applicable)
- Data analysis for estimate of *Cryptosporidium* log reduction
- Appendices for raw full-scale/pilot-scale analytical and operational data
- Monitoring plan to verify that on-going performance is equivalent to treatment credit. Source water indicators used in the study should be monitored to ensure performance is met.
- Plan for addressing operating conditions (e.g., influent water turbidity) out of the range tested in the study. The DOP test matrix generally sets the range of operating conditions under which the LT2ESWTR treatment credit is applicable. Therefore, it is advisable to develop a plan for addressing potential out-of-compliance conditions. For example, if the influent source water quality conditions ranged from 5 NTU to 25 NTU during the study, the system may plan to make operational adjustments for influent water with turbidity greater than 25 NTU and increase filter effluent monitoring. Any such deviations would be reported to the State.

12.5.4.3 Ongoing Reporting

As discussed previously, if a DOP credit is issued by the State, the credit will be conditional on continuing demonstration of a high level of performance. The DOP Monitoring Plan should be modified to document continuing performance at a reduced sampling frequency, while still capturing critical operating conditions. States may require systems receiving a DOP credit to report operational and progress monitoring data on a routine basis. Operational data should verify that continuous process control and optimization procedures are in place.

The DOP credit is applicable to minimum and maximum raw source water and finished water quality limits defined in the DOP Test Matrix. Routine reporting should be performed to verify that plants operate within these limits. If an exception occurs, it should be reported to the State in a timely manner. Frequent exceptions may prompt the State to require the plant to conduct a comprehensive performance evaluation (CPE) to identify causes and solutions for exceptions.

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13.0 Ultraviolet Light

13.1 Introduction

The use of ultraviolet (UV) light for disinfection of drinking water is a relatively new application in the United States, although used for many years in the wastewater industry. UV disinfection is the process of irradiating water with UV light. The UV light is absorbed by the genetic material of microorganisms, damaging it and preventing the microorganisms from reproducing. UV has been found to be particularly effective against protozoa and bacteria.

In addition to this guidance manual, EPA developed the *UV Disinfection Guidance Manual* that contains detailed information of the design and operation of UV systems and the validation testing that must be conducted for compliance with the LT2ESWTR. This chapter summarizes the requirements for water systems using UV disinfection to achieve compliance with the LT2ESWTR.

13.2 Log Inactivation Requirements

To receive credit for disinfection with UV light, the LT2ESWTR (40 CFR 141, Subpart W, Appendix D) requires utilities to demonstrate through validation testing that the UV reactor can deliver the required UV dose. The testing must determine a range of operating conditions that can be monitored by the system and under which the reactor delivers the required UV dose. EPA developed UV dose requirements for *Cryptosporidium*, *Giardia*, and virus that are used during the validation process (see *UV Disinfection Guidance Manual* for dose requirements and application during validation).

Validation testing is not intended to be site-specific, rather product-specific. As a result, validation testing will likely be conducted by the manufacturer or third party and tested over a range of water quality and flow conditions. As long as the water system operates within those conditions tested, they are achieving the log inactivation credit demonstrated during the validation testing.

13.2.1 Monitoring Requirements

In addition to reactor validation, the LT2ESWTR (40 CFR 141.729(d)) requires utilities to monitor for parameters necessary to demonstrate compliance with the operating conditions that were validated for the required UV dose. At a minimum, utilities must monitor each reactor for flow rate, lamp outage, UV intensity as measured by a UV sensor, and any other parameters required by the State.

13.2.2 Reporting Requirements

The LT2ESWTR requires utilities to report the following (40 CFR 141.730):

- Initial reporting - Validation test results demonstrating operating conditions that achieve the UV dose required for the inactivation credit desired for compliance with the LT2ESWTR.
- Routine reporting - Volume of water entering the distribution system that was not treated by the UV reactors operating under validated conditions on a monthly basis.

13.3 Toolbox Selection Considerations—Advantages and Disadvantages

There are several advantages to using UV disinfection over other technologies for the inactivation of *Cryptosporidium*. UV is a relatively simple to use and highly effective technology for inactivating *Cryptosporidium*. Its main advantages include:

- Ability to achieve up to 3 log *Cryptosporidium* inactivation credit at relatively low operating costs
- Low cost technology for inactivation of *Cryptosporidium*, relative to other toolbox options for disinfection
- Produces no halogenated disinfection byproducts
- Easy to install and requires minimal operator attention or experience

The disadvantages of UV disinfection include:

- A higher dose is required to inactivate virus. If a water system is seeking to obtain 4 log virus inactivation with UV disinfection, operating costs will be higher, possibly offsetting the lower capital costs.
- Does not provide a residual disinfectant to guard against regrowth or contamination in the distribution system.
- Lamp start-up time after a power outage can be long, at which time the UV system is not operating within validated conditions and thus, not achieving the given log inactivation credit.

13.4 Design and Operational Considerations

A UV disinfection system consists of the UV reactor and a control panel. The reactor consists of UV lamps, quartz sleeves, UV intensity sensors, quartz sleeve wipers, and temperature sensors. The quartz sleeves serve to insulate and protect the lamps. Some reactors come with automatic cleaning mechanisms for the quartz sleeves. Reactors are equipped with UV intensity monitors, flow meters, and occasionally UV transmittance meters to measure the dose being delivered. There are two primary types of lamps available, low-pressure and medium-pressure. Low-pressure lamps emit light at one wavelength (i.e., monochromatic) and operate with the mercury under a vacuum. Medium-pressure lamps are polychromatic and operate at higher temperatures with the mercury at pressures of 100 to 10,000 Torr.

When considering UV disinfection as a treatment option the following design and operational issues should be addressed:

- Source water quality - Fouling of the lamp sleeves and other reactor equipment will affect the frequency of cleaning required and type of cleaning system. Fouling is dependent on hardness, alkalinity, lamp temperature, pH, and certain inorganic constituents (e.g., iron and calcium).
- Power quality - The lamps operate continuously and as long as there is power to the lamps. The quality of power supply should be considered with UV systems. When the lamp loses power, even on the order of seconds, it requires several minutes to recharge, at which time no disinfection is occurring. An uninterruptible power supply (UPS) is often recommended for UV systems to supply backup power during short power interruptions.
- Hydraulic needs and limitations - Headloss through a UV system is dependent on the specific reactor, piping configuration, and flow rate. Typical headloss ranges from 0.5 to 3.0 feet.
- Maintenance - Although maintenance requirements are low relative to other treatment processes, the UV system will need to be taken off-line periodically to inspect and clean lamps and sleeves.

14.0 Membrane Filtration

14.1 Introduction

Microfiltration and ultrafiltration (MF/UF) are membrane processes which remove microorganisms and other contaminants by filtration. Contaminants larger than the pore size of the membrane are retained on the membrane and removed from the water. MF/UF processes that meet the requirements for membrane filtration under the LT2ESWTR will receive *Cryptosporidium* removal credit.

EPA recently published the Membrane Filtration Guidance Manual for systems applying MF/UF for removal of pathogens from public water supplies. The manual provides detailed guidance on applying membrane filtration to comply with the requirements of the LT2ESWTR. Readers interested in detailed information on membrane filtration should consult the Membrane Filtration Guidance Manual. This chapter will focus on the comparison of membrane filtration with other technologies for inactivation of *Cryptosporidium*.

14.2 Log Inactivation Requirements

Most commercially available MF/UF membranes designed for drinking water treatment, have been demonstrated to remove *Cryptosporidium* to detection limits, provided the membrane is intact. Systems that demonstrate membrane integrity through a challenge test before installation and through daily membrane integrity testing during operation will be eligible for 2.5 log additional credit for *Cryptosporidium* removal under the LT2ESWTR.

14.3 Toolbox Selection Considerations

MF/UF is a highly efficient technology for removing pathogens and other particulates from drinking water. Its main advantages are listed below:

- Essentially complete removal of all particles larger than the exclusion characteristic of the membrane
- Minimal installation effort when supplied as skid-mounted package plants
- Minimal operator attention and training needed when supplied with fully automated controls
- Forms no disinfection byproducts because it is a physical removal process

MF/UF is an advanced technology and can be more expensive than conventional technologies. Its major disadvantages are:

- Total cost may exceed that of conventional technologies
- Membrane fouling may limit application in some cases
- Does not provide a disinfectant residual in the distribution system

14.4 Design Considerations

Membrane systems are usually supplied in skid-mounted packages. The package typically contains the membrane units, a pre-filter for removal of large particles, low pressure feed pumps, high pressure backwash pumps, a chemical cleaning system, a chlorination system, and a backwash residuals handling and disposal system.

A major design variable for membrane systems is the permeate flux. MF/UF membranes are designed to operate within a specific range of pressures and fluxes, and a membrane system must be designed to operate within these specifications. Pilot studies are often performed to find the optimal combination of flux, pressure, pretreatment, and cleaning interval for a particular application. Flux through a membrane is highly temperature dependent, so the average, minimum, and maximum temperature of the water to be treated must be considered when designing the system. The flux and the desired flow rate are used to determine the size and number of membrane units required. Water with high turbidity or high TOC levels can foul membranes, causing poor performance and shortening membrane life. If MF/UF is installed after conventional treatment in the treatment train, high turbidity levels should not be a problem. TOC, however, may still be a problem, even after conventional filtration. If there are high TOC levels, pretreatment should be considered. If the membrane process is being relied upon to remove viruses as well as bacteria and protozoa, UF membranes will be needed. Considerations should also be made for treatment and/or disposal of backwash residuals.

14.5 Operational Considerations

In operating a membrane system, there are several factors that must be balanced. Operating at higher pressures will allow greater flow rates. It will also result in greater operating costs and increased cleaning and backwash frequency. Operating at lower pressures may result in reduced cleaning and backwash frequency but increased area requirements. To ensure the unit is working properly, regular integrity testing of the membrane should be conducted. While indicators such as turbidity can be useful, the integrity of the membrane should be directly tested at least daily. Even with pretreatment, membranes will eventually foul. Periodic cleaning of the membranes will improve membrane performance and life. The appropriate length of time between cleanings can be determined by monitoring the long term decrease in productivity and backwash efficiency.

Appendix A

Site Specific Determination of Contact Time for Chlorine Dioxide and Ozone

A water system may perform a site specific study to generate a set of chlorine dioxide or ozone CT values for that site if it believes those developed by EPA do not reflect the true inactivation achieved. Such a study would involve measuring actual *Cryptosporidium* inactivation under site conditions, with a full range of temperature and contact times. If accepted by the State, the CT values may be used instead of those developed by EPA.

The LT2ESWTR does not specify any requirements for the chlorine dioxide or ozone site-specific study, only that it be approved by the State (40 CFR 141.729(b)(3) and (c)(3)). This appendix describes the different elements of a study and discusses some of the issues involved in the statistical analysis of the results.

A.1 Experimental Design

Experiments should be conducted with water that is representative of the water to be treated with respect to all conditions that can affect *Cryptosporidium* inactivation. Inactivation experiments should be performed with water exerting the highest oxidant demand (i.e. spring run-off or summer conditions) at high temperature to obtain the worst-case scenario in terms of chlorine dioxide or ozone demand/decay rate. In addition, experiments should also be conducted with water obtained during the winter months at the lowest temperatures observed at the treatment plant. These experiments would allow for the determination of the highest CTs that would be necessary to achieve the required level of inactivation. Additional experiments may be necessary to characterize the effects of other water quality parameters.

In order to obtain the most challenging water to assess the chlorine dioxide or ozone process, a predetermined testing schedule should be established based on source water TOC and UV₂₅₄ levels. Testing can occur when source water values for these parameters fall within defined worst-case ranges. Experiments should then be performed in the laboratory at worst-case temperatures for a given month.

In order to obtain a complete data set, testing should occur at least every other month over the course of an entire year. Each sample date should be determined by the first time the TOC or UV₂₅₄ levels are within 75 percent of the maximum historical value for that month. At the time of sampling, sufficient water should be acquired to allow for three sets of experiments to be conducted, with each experiment having six data points (CT values) and a control. Two independent sets of experiments should be conducted with the water. Should significant discrepancies develop between the data sets, a third set of experiments would need to be conducted. An example experimental matrix is provided in Table A.1.

Table A.1 Example Experimental Test Matrix

Date	Temperature to be Tested (Historical Record)	Water Quality Criteria	Schedule of Experiments		
			Test 1	Test 2	Test 3
February	Lowest Annual	TOC or UV ₂₅₄ > 75% of max historical value	X	X	If Required
April	Highest in April	Same	X	X	If Required
June	Highest in June	Same	X	X	If Required
August	Highest Annual	Same	X	X	If Required
October	Highest in October	Same	X	X	If Required
December	Lowest in December	Same	X	X	If Required

A.2 Experimental Procedure

A.2.1 Preparation of oocysts

High oocyst quality is imperative to the success of the study because sub-standard oocysts could dramatically affect the data in a way that would underestimate the CT required to achieve a desired level of inactivation. Traditionally, *Cryptosporidium parvum* oocysts are derived from two host sources, bovine and rodent. The most common strain of *Cryptosporidium parvum* used to date is the Iowa strain, developed by Dr. Harley Moon. It is recommended that the utility perform all experiments using fresh (< 1 month old) Iowa-strain oocysts obtained from a reputable supplier. The utility should ensure that after purification the supplier stores the oocysts at 4° C in a solution of dichromate or 0.01 M phosphate buffer saline solution (pH 7.4) containing two antibiotics (1,000 U/mL penicillin, and 1,000 mg/mL streptomycin), and an antimycotic (2.5 mg/mL amphotericin B). The oocysts should be shipped in a cooler on ice to the utility via next-day service. Upon arrival, the oocysts should be placed in a refrigerator and stored at 4° C until needed.

When ready for use, the oocysts should be suspended in 0.01 M pH 7 buffer and centrifuged at a relative centrifugal force of approximately 1,100 for at least 10 minutes. Following centrifugation, the oocysts should be aspirated and re-suspended in the buffer, then centrifuged again at the same

conditions. This step should be repeated once more to remove as much of the antibiotic or dichromate solution as possible. Following the last aspiration, the oocysts should be re-suspended in approximately 10 mL of the pH 7 buffer. The oocysts should then be stored at 4° C until the experiment is initiated. The oocysts should be vortexed thoroughly prior to initiation of the experiment. Additional details regarding this procedure can be found in Rennecker et al. 1999.

A.2.2 Source Water Preservation

Testing should be conducted as close as possible to the date that the experimental water is collected. If testing is to be performed at a location other than the utility where the water was collected, the water should be sent to the laboratory via an overnight delivery service and stored at 4 degrees Celsius until the start of testing.

A.2.3 Experimental Apparatus

A.2.3.1 Chlorine Dioxide

It is recommended that chlorine dioxide be generated using the equipment and procedures outlined in Standard Methods for the Examination of Water and Wastewater, APHA 1998. With this as a basis, all inactivation experiments using chlorine dioxide should be performed using a batch-reactor configuration. An example of such a system is provided by Ruffell et al. 2000. This system uses an enclosed recirculating water bath to maintain the desired temperature inside the reactor vessels, which consist of 2-liter amber glass bottles. During the experiment, care should be taken to minimize the exposure of the reactors to light. Mixing of the reactor contents is provided with a magnetic stir bar and stir plate.

A.2.3.2 Ozone

Inactivation experiments can be performed with either a semi-batch or batch reactor configuration. When performing experiments with a semi-batch system, it is recommended that analytical components similar to those described by Hunt and Mariñas (1997) be used. Using this system, the reactor vessel containing the experimental water is maintained at the experimental temperature by immersion in a water bath. Ozone can be generated from either compressed air or oxygen and passed through a continuously-stirred glass bottle, which serves to dampen the effect of fluctuating ozone concentration. The ozonated gas leaving the dampening bottle is then introduced to the experimental water via a fine-bubble diffuser. The ozonated water is stirred continuously using a magnetic stirring plate and a stir bar.

It is recommended that inactivation experiments performed using a batch reactor configuration use analytical components similar to those described by Kim (2002). This reactor used a 100-mL gas-tight syringe to prevent ozone in solution from volatilizing into the atmosphere. The temperature inside the reactor is held constant by immersion in a recirculating water bath, and mixing is provided by a stir bar in the syringe controlled by a magnetic stir plate. Ozone can be produced from either compressed air or oxygen. A concentrated ozone stock solution should be prepared using distilled de-ionized or reverse osmosis-filtered water.

Other, less complex, batch reactor systems are also available which simply use an open vessel such as an Erlenmeyer flask or beaker (Finch et al. 1993a). With these systems, the reactor containing the experimental water is typically maintained at the desired temperature using a water bath. An ozonated solution, prepared with distilled de-ionized or reverse osmosis water, is added to the experimental water, and the ozone dose is measured from the diluted experimental water. When using this type of batch-reactor configuration that is open to the atmosphere, the user should take into account that ozone is lost to volatilization. This loss of ozone should be considered and minimized when performing any inactivation or demand/decay experiment.

A.2.4 Inactivation experiments

The CT values obtained from each of the site-specific inactivation experiments are expected to be similar to those provided in the standard LT2ESWTR tables. Therefore, utilities wishing to determine site-specific inactivation data are advised to use the standard tables as a baseline. Each experiment should be designed such that six data points span the range of the “standard” inactivation curve for a given temperature. One “control” point with no disinfectant should also be taken.

A.2.4.1 Chlorine Dioxide

An experimental protocol developed from Ruffell et al. 2000 is provided here as an example. The reactor bottle should be filled with experimental water to a total volume corresponding to the desired sample volume times the number of samples expected per bottle (6 is recommended). The bottle is then placed in the water bath and allowed to equilibrate to the target experimental temperature. At this point, chlorine dioxide stock solution is added to the reactor bottle at the target dose. The reactor bottle is then capped to minimize chlorine dioxide volatilization. The chlorine dioxide concentration is measured approximately 10 min after dosing. An experiment was started by adding approximately a pre-determined number of oocysts to the reactor that will be sufficient for at least six data points. Note the volume of the oocyst aliquot should be less than 1 mL. Samples are then taken periodically at the contact times that correspond to the desired CT. The samples are immediately filtered through a 1µm filter. The filter is then placed in a clean 50 mL beaker and rinsed with

approximately 15 mL of the dilute surfactant. The resulting oocyst suspension is transferred into a sterile 15 mL centrifuge tube.

These steps are repeated at various contact times corresponding to target CT parameters. After the last sample is taken, the chlorine dioxide dose is measured again. “Control” samples are also taken for each experiment by placing a sample of oocysts inside a similar reactor containing the experimental water minus the disinfectant at the target temperature. The oocysts are typically exposed to this condition for the duration of the experiment and subsequently processed for viability assessment with methods similar to those for the disinfected samples.

A.2.4.2 Ozone

If a semi-batch reactor configuration is used, the protocol described by Rennecker et al. (1999) is recommended. The protocol is described briefly as follows. Ozonated gas is applied to the temperature-acclimated experimental water via a fine bubble diffuser. The ozone gas concentration is adjusted to achieve steady-state at dissolved ozone concentrations representative of what would be observed at the facility. The actual dissolved ozone concentration achieved for each experiment is measured. Mixing of the ozonated water is performed with a magnetic stir bar and stirring plate. An inactivation experiment is initiated by injecting a suspension containing a sufficient number of oocysts into the reactor, and ends by simultaneously removing the bubble diffuser and injecting a quenching agent. It should be noted that the number of oocysts necessary for each data point is dependent on the viability assessment method selected. Oocysts are then removed from the quenched solution by filtration through a 1 µm filter. The reactor is then rinsed with approximately 50 mL of a dilute surfactant, and then again with approximately 100 mL of the experimental water to remove any residual surfactant. Both eluents are passed through the filter that is then placed in a clean 50 mL beaker and rinsed with approximately 15 mL of the dilute surfactant. The resulting oocyst suspension is transferred into a sterile 15 mL centrifuge tube. These steps are repeated at various contact times corresponding to target CT parameters (i.e., the product of dissolved ozone concentration and contact time).

Control samples are prepared with each daily experimental set by shutting off the ozone generator, but allowing the oxygen gas to flow through the system. Oxygen gas is allowed to by-pass the semi-batch reactor after shutting off the generator to purge residual ozone gas from the system. All other conditions used for the control are consistent with the experimental conditions previously described. The “contact” time for control samples is 1 minute. After completion of the experiment, the samples are generally centrifuged at 1,100g for 10 minutes and stored in a phosphate buffer solution for a period of time not to exceed 48 hours prior to viability assessment procedures.

Experiments performed with a head-space free reactor can follow the following protocol (described previously in Kim 2002). The experimental temperature is maintained by immersing the 100-mL syringe, which serves as the reactor in a water bath. Mixing inside the reactor is provided

using a stir bar and magnetic stir plate. The syringe is filled with the experimental water containing enough oocysts for all six data points. At this point, an aliquot of temperature-adjusted ozone stock solution of known concentration is added. Samples are then taken at time intervals corresponding to the pre-determined estimated CT using a syringe containing a quenching reagent. The samples are then processed using filtration and centrifugation, similar to those described above. A “control” should be performed for each experiment by placing the same number of oocysts in the experimental water at the desired temperature. The oocysts should remain there for a period of time equal to the duration of the inactivation experiment. After this time, the oocysts should be processed in a manner consistent with the disinfected samples.

Experiments performed with batch reactor components that are not head-space free typically follow a similar, although less complex protocol. An example of such a system and the associated experimental protocol can be obtained from Finch et al. 1993a.

It should be noted that for all batch-reactor systems, a careful characterization of the ozone demand and decay kinetics of the experimental water should be performed prior to any disinfection testing. In addition, it is also recommended that ozone concentration samples be procured alternately between inactivation samples to verify ozone concentrations observed during the disinfection study.

A.2.5 Sample Processing

After procuring each sample point, the samples should be stored at 4° C until the end of the experiment. At the end of each experiment, the samples should be centrifuged at a relative centrifugal force of 1,100 for at least 10 minutes to remove quenching agents or surfactants. Following centrifugation, the samples should be carefully aspirated and re-suspended in 0.01 M pH 7 buffer solution. The samples should be stored at 4 degrees until the time of viability assessment.

A.2.6 Viability Assessment

Determining the viability of oocysts for varying levels of disinfection is one of the most critical components of the inactivation experiments. At present, there are three methods available to assess *Cryptosporidium parvum* viability, each presenting unique advantages and disadvantages. These methods include the following techniques:

- Animal infectivity
- Cell culture (*in vitro* infectivity)

- *In vitro* excystation

The most established of these methods is animal infectivity. This viability assessment method typically involves inoculating immuno-suppressed neonatal mice with varying numbers of oocysts exposed to a particular CT. After a certain “incubation” period, the mice are then sacrificed and their intestinal tracts are examined for signs of *Cryptosporidium*-induced infection (cryptosporidiosis). The primary benefit of this method is that it demonstrates that the treated oocysts are capable of reproduction inside a mammalian host and therefore are able to induce an infection. One criticism of this method is that although an infection is capable of being observed, mouse infectivity has not been correlated to human infectivity. In addition, the protocol associated with this method is difficult and expensive. It requires specialized laboratory training, facilities, and equipment. An example of this protocol can be found in Finch et al. 1993b.

A second method used to assess the viability of *Cryptosporidium parvum* is known as *in vitro* infectivity or cell culture. At present, cell culture methodologies used for this purpose are based on either microscopic evaluation (Slifko et al. 1997) or polymerase chain reaction (PCR) (Rochelle et al. 1997). The first step in using cell culture to assess oocyst viability involves applying the treated oocysts to a lawn of cells (typically derived from human or canine cell lines). After an incubation period, using microscopic evaluation-based culture methods, the cells are stained with fluorescent chemicals and then examined microscopically for various cryptosporidium life stages. The presence of these life stages suggests that the oocysts were capable of reproduction and thus were viable and likely able to cause an infection in humans.

When using a PCR-based technique, after incubation the cells are processed and the *Cryptosporidium parvum* RNA is extracted. Infectivity is then determined by targeting specific genetic sequences in the RNA. The primary advantage of using cell culture to assess *Cryptosporidium parvum* infectivity is that it can measure very low concentrations of oocysts. Therefore, cell culture is capable of demonstrating high levels of inactivation. In contrast, the disadvantages associated with using cell culture include a lack of agreement over the preferred cell lines and viability assessment technique. In addition, there has been no extrapolation between cell culture techniques and human infectivity. Lastly, cell culture techniques are complex and typically require specialized equipment and rigorous training, which makes this procedure somewhat expensive.

A third method known as *in vitro* excystation has also been developed to assess the viability of *Cryptosporidium parvum* (Rennecker et al. 1999). This method involves exposing oocysts to a simulation of a mammalian digestive tract. Following the simulation, the oocysts are then examined microscopically for oocyst life stages that are indicative of viability. The advantages of this method are that it is cost-effective, offers the ability to rapidly develop data, and requires minimal training. The main disadvantage of the method is that of the three methods described, *in vitro* excystation has the least similarity to an actual infection. However, it should be noted that in spite of this fact, two

published studies have shown that inactivation data obtained with *in vitro* excystation closely matches animal infectivity and/or cell culture data (Rennecker et al. 2000, Owens et al. 1999).

A.3 Statistical Analysis

A general approach for calculating a set of CT values involves the following steps:

- 1) Fitting an inactivation model(s) to the experimental inactivation data (for the entire year).
- 2) Calculating the predicted average CT requirements from the best fit model.
- 3) Calculating and applying a factor of safety for the average predicted CT requirement.

One approach by Clark et al. (2002) used a one-parameter Chick-Watson model to fit experimental data sets and develop standard CT curves, relative to inactivation level and temperature. As described in the LT2ESWTR Preamble, EPA used the Clark et al. approach for developing CT values but adjusted the analysis to account for different types of uncertainties and variability inherent in the data. EPA wanted to account for variability among different water matrices and oocyst strains, but not variability within the same group (i.e., same oocyst lot and water), and uncertainty in the regression. While such a complex approach may not be necessary for a site-specific study, the water system should be aware of the uncertainties and variability of the experimental data and use a statistical method that builds in a reasonable safety factor to ensure public health is protected.

Two types of confidence bounds that are commonly used when assessing relationships between variables, such as disinfectant dose (CT) and log inactivation, are confidence in the regression and confidence in the prediction. Confidence in the regression accounts for uncertainty in the regression line (e.g., a linear relationship between temperature and the log of the ratio of CT to log inactivation). Confidence in the prediction accounts for both uncertainty in the regression line and variability in experimental observations—it describes the likelihood of a single future data point falling within a range. Bounds for confidence in prediction are wider (i.e., more conservative) than those for confidence in the regression. Depending on the degree of confidence applied, most points in a data set typically will fall within the bounds for confidence in the prediction, while a significant fraction will fall outside the bounds for confidence in the regression.

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Ozone CT Methods

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Abbreviations

ϵ	Molar absorbance expressed as $M^{-1} \text{ cm}^{-1}$.
BrO_3^-	Bromate ion
$C_{\text{eff}}T_{10}$	Chamber effluent ozone residual in mg/L times chamber T_{10} time in minutes
Co-current chamber	A chamber in an ozone contactor where the water is flowing upward and the ozone gas bubbles are rising. The direction of flow of the water and the gas is the same.
Counter-current chamber	A chamber in an ozone contactor where the water is flowing downward and the ozone gas bubbles are rising. The direction of flow of the water is in the opposite direction of the gas flow.
CSTR	Completely Stirred Tank Reactor – fully mixed volume
CT	The product of Concentration and Time in mg/L-min
DBP	Disinfection byproduct
Half-life or HL	The time that it takes for the ozone residual to decrease by 50%. It is calculated as: $\text{HL} = \frac{\text{Ln}(0.5)}{k^*}$, where k^* = first-order ozone decay coefficient
HDT	Hydraulic detention time calculated as the volume divided by the flow. When volume is expressed in gallons, and flow expressed in gallons/minute, then the calculated HDT is in minutes
In-situ sample ports	Sample ports that take a sample from the flow of the chamber, typically through tubing that projects into the flow
k^*	The first-order ozone decay coefficient, min^{-1} .
k_{10}	Log-base-10 value of the lethality coefficient for the inactivation of <i>Cryptosporidium</i> , <i>Giardia</i> or virus with ozone. The units of k_{10} in this document are L/mg-min.
-Log (I/I ₀)	Log inactivation. Negative log-base-10 of the survival rate (N/N ₀) of the microorganisms, where I ₀ is the number of viable organisms entering the contactor, and I is the number of viable organisms leaving the contactor.
Q	Water flow – usually expressed in gallons per minute (gpm) or million gallons per day (MGD)
Up flow chamber	A chamber within an over-under baffled bubble-diffuser ozone contactor in which the direction of water flow is upward.
V	Volume of the contacting zone in question – usually expressed in gallons or million gallons.

B.1 Introduction

B.1.1 Background

Appendix O of the Surface Water Treatment Rule (SWTR) Guidance Manual (USEPA 1991) includes a description of different methods for determining inactivation credit using an ozone contactor. These methods differ in the level of effort associated with them and, in general, the ozone dose needed to achieve a given level of inactivation. This appendix provides guidance to help water systems select the more appropriate methods for their ozone process. More importantly, it builds on the information presented in the SWTR Guidance Manual with detailed descriptions of the extended continuous stirred tank reactor (CSTR) method. Appendices D and E compliment this appendix with descriptions of ozone residual sampling and laboratory analysis (Appendix D) and derivations of equations used in the extended CSTR and SFA approaches (Appendix E).

The three methods for calculating LT2ESWTR ozone inactivation credit, presented in Chapter 11 and this appendix, are described below.

1. **T₁₀**--calculates CT through a contactor assuming hydraulic conditions similar to plug flow and can be used with or without tracer study data. T₁₀ is the time it takes for 90 percent of the water to pass the contactor. Even in well-baffled contactors, the T₁₀ is most often less than 65 percent of the average hydraulic detention time (HDT) through the contactor, and generally underestimates the true CT achieved. (The T₁₀ approach is described in Chapter 11, section 11.3.)
2. **CSTR**--calculates log inactivation credit using hydraulic detention time. It is applicable to contactors that experience significant back mixing or when no tracer study data are available. EPA recommends using this method (or the Extended CSTR) when no tracer study data are available. (The CSTR approach is described in Chapter 11, section 11.3.)
3. **Extended CSTR**--a combination of the CSTR and SFA approaches. It utilizes the hydraulic detention time for the contact time and incorporates the ozone decay rate to calculate concentration. It is not applied to chambers into which ozone is introduced.

While this guidance manual describes three methods, other methods or modifications to these methods may be used at the discretion of the State. A fourth method, the Segmented Flow Analysis approach, is under consideration by EPA, but the details of the approach are not final. EPA is requesting comment on the approach and any appropriate safety factors to ensure the inactivation credit calculated using the method is actually achieved.

B.2 Selection of Methods for Calculating Inactivation Credit

Selecting the appropriate methods to use depends on the configuration of the ozone contactor and amount of process evaluation and monitoring that a water system is willing to undertake. It is also possible that combinations methods can be used. For contactors with multiple segments it is likely that the CT of one or two segments would be calculated using either the T_{10} or CSTR methods, while the CT for the remaining segments would be calculated with the Extended-CSTR.

Of the three methods described in the previous section, the Extended CSTR is the most complex method. The Extended-CSTR approach requires measurements of the ozone concentration at a minimum of three points within the contactor to develop a predicted ozone concentration profile through the contactor. The contact time is based on the hydraulic detention time of the contactor and an assumption of completely mixed flow. While many mathematical principles are discussed in these methods, their implementation is fairly straightforward. In fact, the methods presented in this appendix can be programmed into a conventional spreadsheet or a plant computer control system.

The following tables define the types of chambers potentially present in an ozone contactor and show the recommended methods for calculating the inactivation credit achieved. Only the T_{10} or CSTR methods can be applied to dissolution chambers. However, they can be applied to the reactive chambers as well. In general the T_{10} method should be used unless significant back mixing occurs in the chamber. If no tracer test data are available, it is recommended that the CSTR method be used. The Extended-CSTR method is applied over a minimum of three consecutive reactive chambers. Table B.1 shows the recommended methods.

**Table B.1 Applicable Methods and Terminology for Calculating the
Log Inactivation Credit**

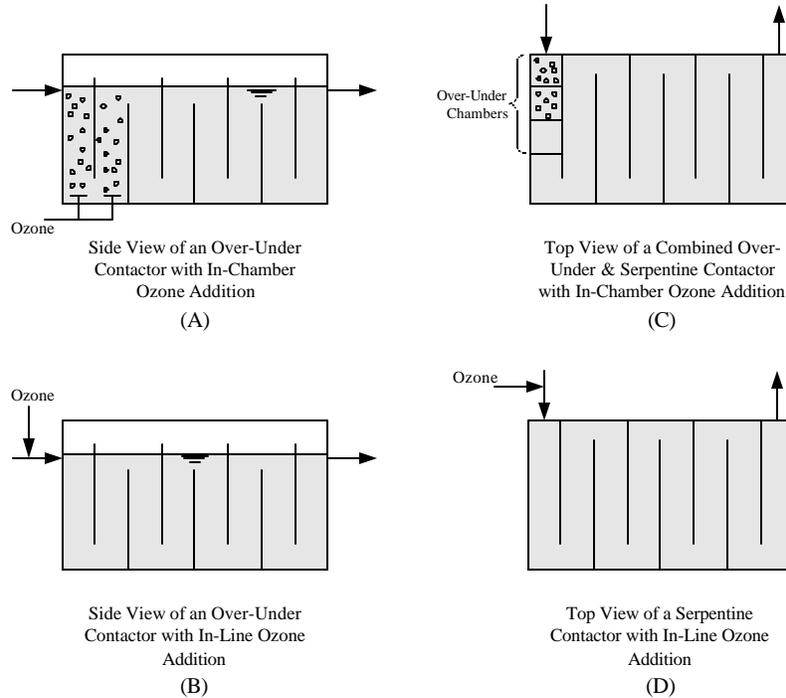
	Section Description	Terminology	Method for Calculating Log Inactivation	Restrictions
No Tracer Data	Chambers where ozone is added			
	First chamber	First Dissolution Chamber	No log inactivation credit is recommended	None
	Other chambers	Co-Current or Counter-Current Dissolution Chambers	CSTR Method in each chamber with a measured effluent ozone residual concentration	No credit is given to a dissolution chamber unless a detectable ozone residual has been measured upstream of this chamber
	Reactive Chambers			
	≥ 3 consecutive reactive chambers	Extended-CSTR Zone	Extended-CSTR Method in each chamber	Detectable ozone residual should be present in at least 3 chambers in this zone, measured via in-situ sample ports. Otherwise, the CSTR method should be applied individually to each chamber having a measured ozone residual
< 3 consecutive reactive chambers	CSTR Reactive Chamber(s)	CSTR Method in each chamber with a measured effluent ozone residual concentration	None	
With Tracer Data	Chambers where ozone is added			
	First chamber	First Dissolution Chamber	No log inactivation is credited to this section	Not applicable
	Other chambers	Co-Current or Counter-Current Dissolution Chambers	T₁₀ or CSTR Method in each chamber	No credit will be given to a dissolution chamber unless a detectable ozone residual has been measured upstream of this chamber
	Reactive Chambers			
	≥ 3 consecutive chambers with in-situ sample ports	Extended-CSTR Zone	Extended-CSTR Method in each chamber	Detectable ozone residual should be present in at least 3 chambers in this zone, measured via in-situ sample ports. Otherwise, the T₁₀ or CSTR method should be applied to each chamber having a measured ozone residual
< 3 consecutive chambers	T ₁₀ or CSTR Reactive Chamber(s)	T₁₀ or CSTR Method in each chamber	None	

B.3 Ozone Contactor Configurations

Ozone contactors are designed in a wide variety of configurations. Different configurations are adaptable to the Extended-CSTR approach, but implementation details vary with contactor configuration. It is important for a water system to identify the type of configuration and become familiar with the terminology used in this guidance manual.

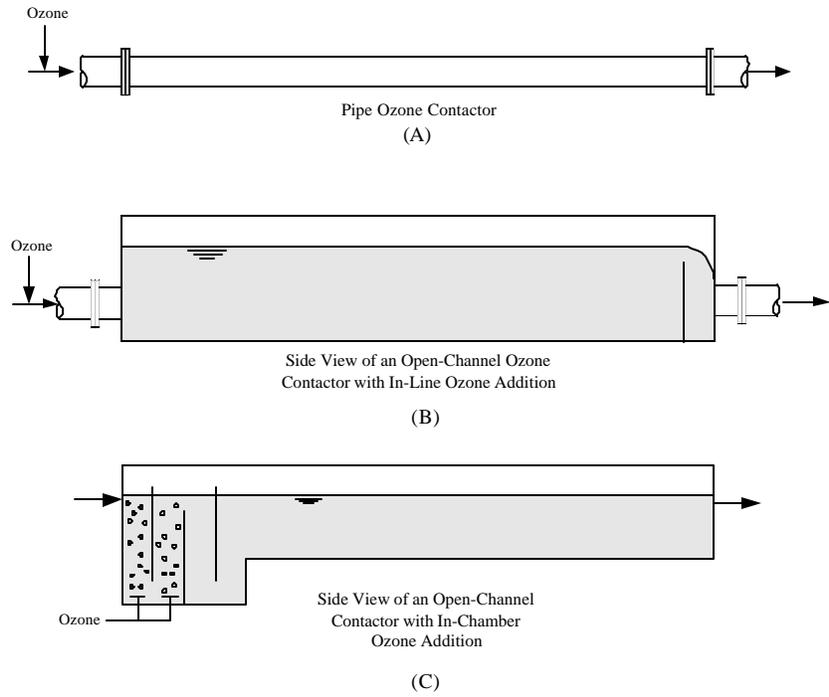
Figure B.1 shows configurations with multiple, consecutive well-defined reactive chambers. The water flow pattern in such contactors can be an “over-under” pattern, a “serpentine” pattern, or a combination of both. Gaseous ozone is added to the water by one of two procedures. Gaseous ozone can be injected into the influent water before the water enters the contactor, a process often called “in-line” ozone addition (see schematic B & D in Figure B.1). Alternatively ozone enriched gas can be bubbled into one or more chambers, a process called “in-chamber” ozone addition (see schematic A & C in Figure B.1). In-chamber ozone addition takes place in chambers that have an over-under flow pattern and not in chambers that have a serpentine flow pattern (Figure B.1-C) in order to ensure full and complete ozone dissolution into all the water flow. These so-called bubble columns can be counter-current or co-current, describing the directional flow of the water with respect to the upward flowing bubbles. Note, Figure B.1 only shows example configurations; size and geometry of the chambers will vary.

Figure B.1 Schematics of Typical Configurations of Ozone Contactors with Multiple Chambers



In contrast to the multi-chamber configuration, ozone contactors may also be comprised on only one or two reactive chambers. Examples of such contactors are shown in Figure B.2, which include a closed-pipe contactor (see schematic A) and two open-channel contactors (see schematics B & C). All three contactors include a long and narrow water flow path that promotes plug-flow hydraulic characteristics. As with multi-chamber contactors, ozone can be added in-line, or in-chamber. Contactors A and B illustrate in-line ozone addition. Contactor C illustrates in-chamber ozone addition.

Figure B.2 - Schematics of Example Single- or Dual-Chamber Ozone Contactors



B.4 Extended-CSTR Approach for Ozone Contactors

B.4.1 Introduction

The method described in this chapter represent a more sophisticated approach to calculating inactivation credit in an ozone contactor as compared to the T_{10} and CSTR approaches. This approach could potentially provide a higher and more accurate estimate of the level of *Cryptosporidium* inactivation than that obtained using the T_{10} approach. The potential benefits of using these more sophisticated measures are lower ozone doses and lower ozonation disinfection byproducts, (e.g. bromate). However, as a consequence of this added sophistication, a higher degree of system evaluation and monitoring is needed for a given inactivation credit. Whether use of these more sophisticated approaches actually benefit the utility depends on many factors including the sought-after level of inactivation, the reactor configuration, and the water quality.

The approach described in this chapter is called the ***Extended-CSTR Approach***. Certain aspects of this methodology was introduced in Appendix O of the SWTR Guidance Manual. However, the material presented here greatly expands upon the SWTR Guidance Manual, and may provide beneficial new tools for the utility.

B.4.2 Overview of System Evaluation and Monitoring

The Extended-CSTR approach relies on modeling ozone decay reactions through ozone contactors. In principal, the kinetics of ozone decay in the contactor is modeled in concert with the hydrodynamics of the ozone contactor, which is assumed to be that of an ideal CSTR. This approach is applied only to “reactive chambers” within a contactor.

B.4.3 Extended-CSTR Approach - Ozone Contactors without a Tracer Test

In the event that an approved set of tracer test results is unavailable for an ozone contactor, the utility may choose one of the following two options:

1. Use the ***CSTR method*** to calculate the log inactivation across each individual chamber.
2. Use the ***Extended-CSTR approach*** to calculate the log inactivation across each individual chamber.

The choice of using the CSTR approach, the Extended-CSTR approach, or a combination of the two greatly depends on the reactor configuration and the manner in which the measurement of ozone residuals is attained. Briefly, for CSTR approach, concentrations are measured for each chamber where log inactivation is calculated. In contrast, for the chambers in

the Extended-CSTR approach, ozone concentrations of each chamber are calculated through modeling of the ozone decay. This section describes the appropriate application of the CSTR approach and Extended-CSTR approach to calculate the log inactivation credit across the contactor.

B.4.3.1 Classification of the Chambers and Contactor Zones

The contactor should be divided into specific sections, or zones, to properly calculate the inactivation credit across a conventional contactor. To ensure clarity, certain terminology is adopted for unique sections of an ozone contactor, as presented in Table B.1.

Figure B.3 shows an example schematic of a 10-chamber over-under baffled, multi-chamber ozone contactor with in-chamber ozone addition. Ozone is being added in Chambers 1 and 4 only in this example.

Chamber 1 is classified as a “First Dissolution Chamber” and it is recommended that no disinfection credit be granted for this chamber. Rapid, initial ozone reactions and the transitional development of the ozone residual occur in the first dissolution chamber. As such, a representative dissolved ozone profile is difficult to estimate without multiple sample ports along the bubble column.

The second and third chambers in the contactor shown in Figure B.3 are reactive chambers through which ozone is decaying. These chambers are called “CSTR Reactive Chambers”. The CSTR method is used to calculate log inactivation across CSTR Reactive Chambers when ozone residual values are available from the effluent of the chamber. The CSTR method is described in Chapter 11.

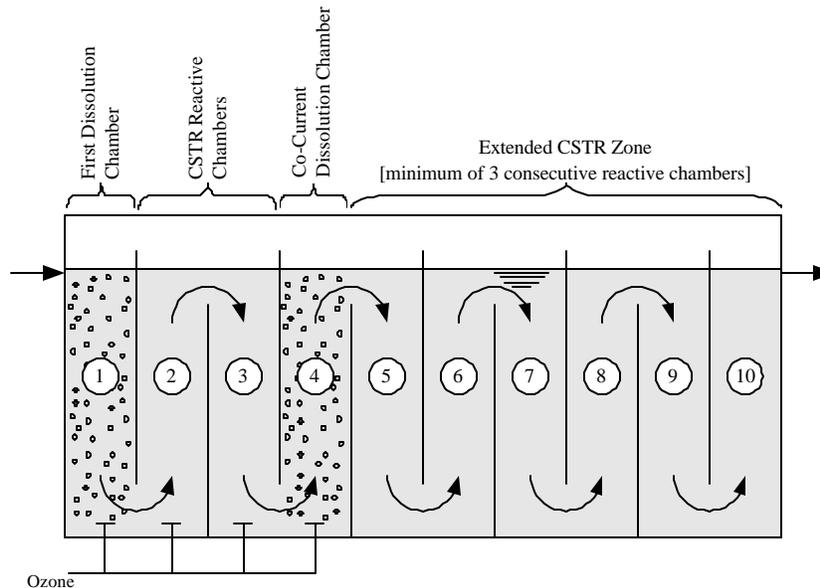


Figure B.3 - Names of the Various Sections of a Multi-Chamber Over-Under Ozone Contactor

The fourth chamber in the contactor shown in Figure B.3 includes ozone addition. This chamber is called a “Co-Current Dissolution Chamber”. It should be emphasized that a chamber is given the “Dissolution Chamber” notation only when ozone residual has been detected at any point upstream of the influent to that chamber. In other words, chamber 4 in Figure B.3 can be classified as a Dissolution Chamber only if ozone residual has been detected at the effluent of either chamber 1, 2, or 3. The CSTR method is used to calculate the log inactivation credit across a Dissolution Chamber. If no ozone residual was detected upstream of this chamber location, then chamber 4 takes on the classification of a “First Dissolution Chamber” and as with chamber 1, no log inactivation credit is granted.

Chambers 5 through 10 in the contactor pictured in Figure B.3 represent the “Extended-CSTR zone” since they meet the criterion of containing a minimum of three consecutive reactive chambers. Since tracer data are unavailable, the Extended-CSTR approach is used to calculate the log inactivation across each chamber in this zone. Modeling is used to calculate the ozone residual concentration at the effluent of each chamber within the Extended-CSTR zone. This modeling requires an accurate estimation of the ozone decay coefficient, k^* , and the initial ozone residual at the entrance to the zone, C_{in} . Estimation of these two parameters, which is discussed in sections B.4.3.2.1 and B.4.3.2.2, requires the measurement of three ozone residual values across the minimum span of three chambers.

In the case of a contactor with in-line ozone addition, the entire contactor potentially becomes an Extended-CSTR zone. If the contactor has at least three chambers equipped with in-

situ sample ports and a measurable ozone residual then the requirements for calculating k^* and C_{in} have been met and the entire contactor can be treated as an Extended-CSTR zone. Care should be taken in locating the first ozone sample port such that enough reaction time is allowed for the immediate ozone demand to be fully met before the sample port.

B.4.3.2 Calculating Log Inactivation across an Extended-CSTR Zone

Calculation of log inactivation across an Extended-CSTR zone is handled in much the same manner as it is for a CSTR Reactive Chamber as discussed in Chapter 11. The Extended-CSTR zone comprises three or more individual chambers. Inactivation within each chamber is calculated according to Equation 11-1, exactly as it is for the CSTR chamber above, and the sum of the log inactivation values for individual chambers gives the inactivation across the whole zone. The distinction between a CSTR Reactive Chamber and a chamber that is a component of an Extended-CSTR zone is the manner in which the value for C is obtained. In the case of the CSTR Reactive Chamber, C is obtained from an actual measurement of the dissolved ozone residual at the exit of the chamber (i.e., C_{out}). In contrast, C for a chamber in an Extended-CSTR zone is a calculated value. The procedure for calculating C for an Extended-CSTR zone is described in this section.

The value of C for an Extended-CSTR is calculated using the first-order ozone decay coefficient, k^* , and the ozone residual concentration at the entrance to the zone, C_{in} . Equation B-1 shows how to calculate the ozone residual at the effluent of chamber “X” in an Extended-CSTR zone:

$$C_X = \frac{C_{in}}{\left[1 + k^* \times \frac{[Volume]_{0-X}}{N_{0-X} \times Q} \right]^{N_{0-X}}} \quad (B-1)$$

- where:
- k^* = First-order ozone decay coefficient, min^{-1} , calculated as described in section B.4.3.2.1
 - C_{in} = Calculated ozone residual concentration at the entrance to the Extended-CSTR zone, mg/L, calculated as described in section B.4.3.2.2
 - $[Volume]_{0-X}$ = Volume, in gallons, from the beginning of the Extended-CSTR zone to the effluent of chamber “X”
 - N_{0-X} = Number of chambers from the beginning of the Extended-CSTR zone to the effluent of chamber “X”
 - Q = Water flow through the contactor, gpm

Equation B-1 describes the Extended-CSTR zone between the first chamber (subscript 0) and chamber X as a series of equal-volume CSTR reactors. This is a simplifying assumption that is

based on a balance between ease of implementation and consistency with other provisions within this guidance manual.

Once the values of the ozone residual concentrations at the effluent of each chamber in the Extended-CSTR zone are calculated, Equation 11-1 can then be used to calculate the log inactivation achieved across that chamber. The total log inactivation achieved across the entire contactor is equal to the sum of the log inactivation values calculated for each chamber.

$$-\text{Log} (I/I_0) = \text{Log} (1 + 2.303k_{10} \times C \times \text{HDT}) \quad \text{Equation 11-1}$$

where:

$-\text{Log} (I/I_0)$ = the log inactivation

k_{10} = log base ten inactivation coefficient (L/mg-min)¹

C = Concentration from Table 11-2 (mg/L)

HDT = Hydraulic detention time (minutes)

Because the ozone demand in the water is constantly changing, the values of k^* and C_{in} should be determined every time log inactivation credit is calculated (i.e. at least daily). These parameters are calculated using three measured ozone residuals from three locations within the Extended-CSTR zone.

B.4.3.2.1 Determining the Value of k^*

The ozone decay coefficient, k^* is calculated using ozone sample measurements, taken from in-situ sample ports, and a model of the chamber's hydrodynamics. The following approach assumes that the individual chambers can be modeled as a CSTR (or equal-volume CSTR-in-series if there are more than one chamber between sample ports).

Calculating k^*

The steps outlined below pertain to a contactor with a minimum of three consecutive chambers with measurable ozone residuals. That is, there should be at least three in-situ sample ports from the Extended-CSTR zone with measurable ozone residual. The three ozone residual measurements, C_1 , C_2 , and C_3 , are needed to estimate the value of the ozone decay coefficient, k^* . For example, the Extended-CSTR zone in the contactor shown in Figure B.3 includes chambers 5 through 10. The ozone residual values at any three chambers in that span can be used to represent C_1 , C_2 , and C_3 in this analysis. The following steps should be followed to calculate the k^* value:

¹ k_{10} is calculated from the CT table with the following equation: $\text{Log inactivation} = k_{10} \times \text{CT}$

Step 1 – Use Equation B-2 and residual measurements C_1 and C_2 to calculate the k^* value representing the ozone decay between locations 1 and 2, k_{1-2}^* . (A derivation and explanation of Equation B-2 is presented in Appendix E):

$$k_{1-2}^* = \frac{N_{1-2} \times Q}{[Volume]_{1-2}} \left[\left(\frac{C_1}{C_2} \right)^{\left(\frac{1}{N_{1-2}} \right)} - 1 \right] \quad (B-2)$$

where: k_{1-2}^* = First-order ozone decay coefficient between sampling locations 1 & 2, min^{-1}
 C_1 = Measured ozone residual at location 1, mg/L
 C_2 = Measured ozone residual at location 2, mg/L
 $[Volume]_{1-2}$ = Volume between sampling locations 1 and 2, gallons
 N_{1-2} = Number of chambers between sampling locations 1 and 2
 Q = Water flow through the contactor, gpm

Step 2 – Use residual measurements C_1 and C_3 along with Equation B-3 to calculate the k^* value representing ozone decay between sampling locations 1 and 3, k_{1-3}^* :

$$k_{1-3}^* = \frac{N_{1-3} \times Q}{[Volume]_{1-3}} \left[\left(\frac{C_1}{C_3} \right)^{\left(\frac{1}{N_{1-3}} \right)} - 1 \right] \quad (B-3)$$

where: k_{1-3}^* = First-order ozone decay coefficient between sampling locations 1 & 3, min^{-1}
 C_1 = Measured ozone residual at location 1, mg/L
 C_3 = Measured ozone residual at location 3, mg/L
 $[Volume]_{1-3}$ = Volume between sampling locations 1 and 3, gallons
 N_{1-3} = Number of chambers between sampling locations 1 and 3
 Q = Water flow through the contactor, gpm

It should be emphasized that sampling location 1 should not be at the entrance to the Extended-CSTR zone, but should be at least one chamber into the zone. For example, in Figure B.3, C_1 should not be measured at the entrance to chamber 5, since that is the entrance to the Extended-CSTR zone. Instead, the first Extended-CSTR zone sampling location should be located at the effluent of chamber 5, or downstream of that location. Section O.3.2 of Appendix O of the SWTR Guidance Manual provides guidance on the use of in-situ sample ports for direct ozone measurements.

Step 3 – The value of k^* that is to be used in Equation B-1 will be calculated as the average of k_{1-2}^* and k_{1-3}^* as shown in Equation B-4.

$$k^* = \left[\frac{k_{1-2}^* + k_{1-3}^*}{2} \right] \quad (\text{B-4})$$

It is normal for the individual values of k_{1-2}^* and k_{1-3}^* to be somewhat different. However, it is recommended that they be within the range of 80% to 120% of the average k^* value calculated in Step 3. That is,

$$\frac{\text{abs}\langle k^* - k_{1-i} \rangle}{k^*} \leq 20\%$$

If they are outside this range, the measured residual values should be rejected and new samples should be collected until this quality assurance (QA) criterion is met.

Ozone residual measurement at the three locations might be conducted manually using the Indigo Trisulfonate method, or continuously using on-line ozone analyzers. The Quality Assurance protocols discussed in Appendix D should be implemented to ensure that the ozone residual measurements are accurate.

B.4.3.2.2 Determining the Value of C_{in}

While it is possible to measure the ozone residual at the entrance to the Extended-CSTR zone (e.g., an in-situ sample port), it is not recommended that the measured value be used because it is usually higher than the residual predicted by the first-order decay profile (Amy et al., 1997; Carlson et al., 1997; Hoigné and Bader, 1994; Rakness and Hunter, 2000; Rouston et al., 1998). This phenomenon is commonly attributed to the more rapid initial ozone decay, which is followed by a somewhat slower first-order decay profile. For this reason, the C_{in} representing the ozone decay in the Extended-CSTR Zone should be extrapolated using the downstream measured ozone residual values.

The value of C_{in} can be calculated once the value of k^* is estimated from the three residual ozone measurements. Maintaining the assumption of a first-order decay rate, and again using the CSTR (or equal-volume CSTR-in-series if there are more than one chamber between sample ports) assumption, Equations B-5 through B-7 can be used to estimate the value of C_{in} from the three measured ozone residual concentrations:

$$C_{in,1} = C_1 \times \left[1 + k^* \times \frac{[Volume]_{0-1}}{N_{0-1} \times Q} \right]^{N_{0-1}} \quad (B-5)$$

$$C_{in,2} = C_2 \times \left[1 + k^* \times \frac{[Volume]_{0-2}}{N_{0-2} \times Q} \right]^{N_{0-2}} \quad (B-6)$$

$$C_{in,3} = C_3 \times \left[1 + k^* \times \frac{[Volume]_{0-3}}{N_{0-3} \times Q} \right]^{N_{0-3}} \quad (B-7)$$

where: k^* = Ozone first-order decay coefficient, min^{-1}
 C_1 = Measured ozone residual at location 1, mg/L
 C_2 = Measured ozone residual at location 2, mg/L
 C_3 = Measured ozone residual at location 3, mg/L
 N_{0-1} = Number of chambers between the entrance to the Extended-CSTR Zone and sampling location 1
 N_{0-2} = Number of chambers between the entrance to the Extended-CSTR Zone and sampling location 2
 N_{0-3} = Number of chambers between the entrance to the Extended-CSTR Zone and sampling location 3
 $[Volume]_{0-1}$ = Volume, in gallons, between the entrance of the Extended-CSTR Zone and sampling location 1
 $[Volume]_{0-2}$ = Volume, in gallons, between the entrance of the Extended-CSTR Zone and sampling location 2
 $[Volume]_{0-3}$ = Volume, in gallons, between the entrance of the Extended-CSTR Zone and sampling location 3
 Q = Water flow through the contactor, gpm

The C_{in} value is then calculated as the average of the three values determined by Equations B-5 through B-7:

$$C_{in} = \left[\frac{C_{in,1} + C_{in,2} + C_{in,3}}{3} \right] \quad (B-8)$$

These calculations outline the methodology of the Extended-CSTR approach. A systematic example of the Extended-CSTR approach is presented in section B.4.5

B.4.3.2.3 Quality Assurance for Extended-CSTR Calculations

The Extended-CSTR method depends on ozone residual measurements and an assumption that the contactor hydrodynamics can be modeled as a CSTR in order to predict

ozone concentrations through the contactor. To ensure that the predicted concentrations are accurate, both the measurements and assumptions should be verified. Therefore, QA controls are recommended as described below.

The predicted ozone residual concentration, the parameter C in Equation 11-1, encompasses both the CSTR assumption and ozone measurements. The principal QA issues focus on the prediction of the value of C. As seen in equation B-1, C depends on the parameters k^* and C_{in} . In section B.4.3.2.1, as part of the discussion on the calculation of k^* , it is stipulated that the individual k^* values (i.e., k^*_{1-2} and k^*_{1-3}) should be within 20% of the average value. This QA control is meant to ensure that ozone residual measurements used to calculate the ozone decay profile are consistent with the calculated profile. Since the calculation of C_{in} (Equations B-5 through B-8) depends on k^* , as well as the measured ozone concentrations, the QA criteria for k^* is sufficient for C_{in} . Therefore, no additional QA criteria are necessary for it.

The accuracy of the CSTR assumption cannot be completely verified without conducting a tracer study through the contactor. However, it is recommended that ozone residual measurements be taken at different flows and ozone doses, and k^* and C_{in} be calculated at the different conditions, in order to determine the impact of changing conditions on the predicted ozone decay rate.

Finally, one of the most important aspects of any application of a model towards predicting reactor performance is the confirmation of the model's prediction. This is in essence "model validation." Appendix O of the SWTR Guidance Manual makes several points to this effect. Ideally, model validation would take the form of measuring the actual disinfection of the *Cryptosporidium*. A more practical alternative is to compare the predicted ozone concentrations to measured values. The general recommendation is that the predicted ozone residual should not be greater than 20% of a measured value. Note that this is a one-sided QA control.

The ozone concentration measurements used to calculate k^* and C_{in} cannot be compared to the predicted ozone residuals, since they are interdependent. It is recommended that ozone samples be taken from other sampling locations in the contactor, and those values compared to the calculated C.

B.4.4 Example of Extended-CSTR Application

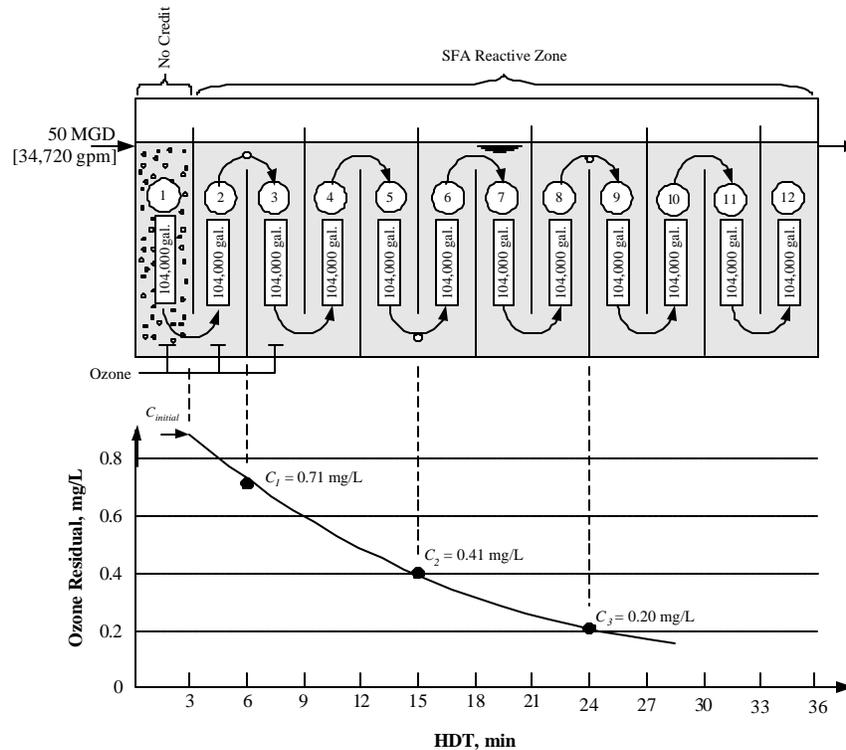
This section provides an example calculating the log inactivation credits using the Extended-CSTR approach.

Example – Extended-CSTR Approach for a Multi-chamber Contactor With In-situ Sample Ports and One Dissolution Chamber

Figure B.6 shows a schematic of a 12-chamber ozone contactor. The contactor is treating 50 MGD of water at a temperature of 20°C. The volumes of the individual chambers are

noted on the schematic. Ozone is added to the first chamber only. The bottom graph in Figure B.6 shows the values of the ozone residual measured at the effluents of chambers 2, 5, and 8.

Figure B.6 - Schematic of the Ozone Contactor and the Measured Ozone Residual Values in Example 1



The *Cryptosporidium* inactivation credit across the contactor is calculated as follows:

Chamber 1 (First Dissolution Chamber) – No inactivation credit is given to the first dissolution chamber.

Chambers 2 through 12 (Extended-CSTR zone) – This zone is classified as an Extended-CSTR zone. The Extended-CSTR calculations (Section 4.3) are applied to determine the log inactivation across each chamber. The following steps are implemented

Step 1: Calculate k^ value* – The k^* value is calculated as described in section B.4.3.3.1 using the three ozone-residual measurements, C_1 , C_2 , and C_3 that are shown in Figure B.6. The values of k_{1-2}^* and k_{1-3}^* can be calculated using Equations B-2 and B-3 as follows:

$$k_{1-2}^* = \frac{N_{1-2} \times Q}{[Volume]_{1-2}} \left[\left(\frac{C_1}{C_2} \right)^{\left(\frac{1}{N_{1-2}} \right)} - 1 \right] = \frac{3 \times 34,720}{[3 \times 104,000]} \left[\left(\frac{0.71}{0.41} \right)^{\frac{1}{3}} - 1 \right] = 0.0670 \text{ min}^{-1}$$

$$k_{1-3}^* = \frac{N_{1-3} \times Q}{[Volume]_{1-3}} \left[\left(\frac{C_1}{C_3} \right)^{\left(\frac{1}{N_{1-3}} \right)} - 1 \right] = \frac{6 \times 34,720}{[6 \times 104,000]} \left[\left(\frac{0.71}{0.2} \right)^{\frac{1}{6}} - 1 \right] = 0.0785 \text{ min}^{-1}$$

The k^* value is then calculated as the average of k_{1-2}^* and k_{1-3}^* as follows:

$$k^* = \left[\frac{k_{1-2}^* + k_{1-3}^*}{2} \right] = \left[\frac{0.0670 + 0.0785}{2} \right] = 0.0728 \text{ min}^{-1}$$

A QA check shows that the values of k_{1-2}^* and k_{1-3}^* are within 8% of the average k^* value of 0.0728 min^{-1} . This value of k^* is within the recommended maximum variability of 20%.

Step 2: Calculate C_{in} value – The value of C_{in} is calculated using the approach described in Section 4.3.3.2. With the value of k^* calculated at 0.0728 min^{-1} , Equations B-5 to B-7 can be used to calculate the C_{in} value as follows:

$$C_{initial,1} = C_1 \times \left[1 + k^* \times \frac{[Volume]_{0-1}}{N_{0-1} \times Q} \right]^{N_{0-1}} = 0.71 \times \left[1 + 0.0728 \times \frac{[104,000]}{1 \times 34,720} \right]^1 = 0.865 \text{ mg/L}$$

$$C_{initial,2} = C_2 \times \left[1 + k^* \times \frac{[Volume]_{0-2}}{N_{0-2} \times Q} \right]^{N_{0-2}} = 0.41 \times \left[1 + 0.0728 \times \frac{[4 \times 104,000]}{4 \times 34,720} \right]^4 = 0.902 \text{ mg/L}$$

$$C_{initial,3} = C_3 \times \left[1 + k^* \times \frac{[Volume]_{0-3}}{N_{0-3} \times Q} \right]^{N_{0-3}} = 0.20 \times \left[1 + 0.0728 \times \frac{[7 \times 104,000]}{7 \times 34,720} \right]^7 = 0.796 \text{ mg/L}$$

Therefore,

$$C_{initial} = \left[\frac{C_{initial,1} + C_{initial,2} + C_{initial,3}}{3} \right] = \left[\frac{0.865 + 0.902 + 0.796}{3} \right] = 0.854 \text{ mg/L}$$

Step 3: Calculate the value of k_{10} – The value of k_{10} for the inactivation of *Cryptosporidium* with ozone at the measured temperature of 20°C can be obtained from Table 11-3 directly and equals 0.2537 L/mg-min. Otherwise the value for k_{10} could be determined using equation 11-2.

Step 4: Calculate the Ozone Residual at the Effluent of Each Chamber – Knowing the values of C_{in} and k^* , the ozone concentration at the effluent of each chamber within the Extended-CSTR zone can be calculated. These values are calculated using Equation B-1:

$$C_X = \frac{C_{initial}}{\left[1 + k^* \times \frac{[Volume]_{0-X}}{N_{0-X} \times Q} \right]^{N_{0-X}}}$$

where C_X is the calculated concentration at the effluent of chamber “X”. For example, the residual concentration at the effluent of chamber 4 is calculated as:

$$C_4 = \frac{0.854}{\left[1 + 0.0728 \times \frac{[3 \times 104,000]}{3 \times 34,720} \right]^3} = 0.473 \text{ mg/L}$$

Note that the Extended-CSTR zone begins at the effluent of Chamber 1, which makes the subscript to [Volume] in the equation above depicted as “1-4”. Table B.10 lists the calculated residual values for each chamber using the same approach, beginning with chamber 2.

Table B.10 –Application of the Extended-CSTR Method to the Example

Vol./Chamber =	104,000	gallons	
Flowrate =	34,720	gpm	
C _{initial} =	0.854	mg/L	
k* =	0.0728	min ⁻¹	
k ₁₀ =	0.2537	L/mg-min	
(1)	(2)	(3)	(4)
Chamber	HDT from Entrance of Zone HDT, min	Calculated Residual mg/L	Log Inactivation
2	3.0	0.701	0.35
3	6.0	0.576	0.30
4	9.0	0.473	0.26
5	12	0.388	0.23
6	15	0.318	0.19
7	18	0.261	0.16
8	21	0.215	0.14
9	24	0.176	0.12
10	27	0.145	0.10
12	33	0.099	0.07
		Sum =	1.9

Step 4: Calculate Log Inactivation – Knowing the values of C, k₁₀, and k*, Equation 11-1 is used to calculate the log inactivation achieved in each chamber in the Extended-CSTR Zone:

$$\text{Log - inactivation} = \text{Log} \left[1 + 2.303 k_{10} C_x \frac{[\text{Volume}]_x}{Q} \right]$$

where C_x is the effluent residual concentration at Chamber X and [Volume]_x is the volume of that chamber. For example, the log inactivation achieved in chamber 4 is calculated as:

$$\text{Log - inactivation} = \text{Log} \left[1 + 2.303 \times 0.246 \times 0.473 \times \frac{104,000}{34,720} \right] = 0.26 \text{ logs}$$

Column (4) in Table B.10 lists the log inactivation values calculated for chambers 2 through 12. The sum of the log inactivation achieved (total of Column 4 in Table B.9) is 1.9 logs.

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Appendix C

Measuring Ozone Residual

Accurate ozone residual data will allow the calculation of correct log-inactivation values and maintain optimized performance. Ozone residual measurements might be inaccurate if sampled or measured incorrectly. Residual measurement Quality Assurance (QA) issues include:

1. Configuration of the ozone sample collection lines within the contactor,
2. Stability of the indigo trisulfonate reagent when analyzing grab samples, and
3. Standardization and maintenance of on-line ozone analyzers.

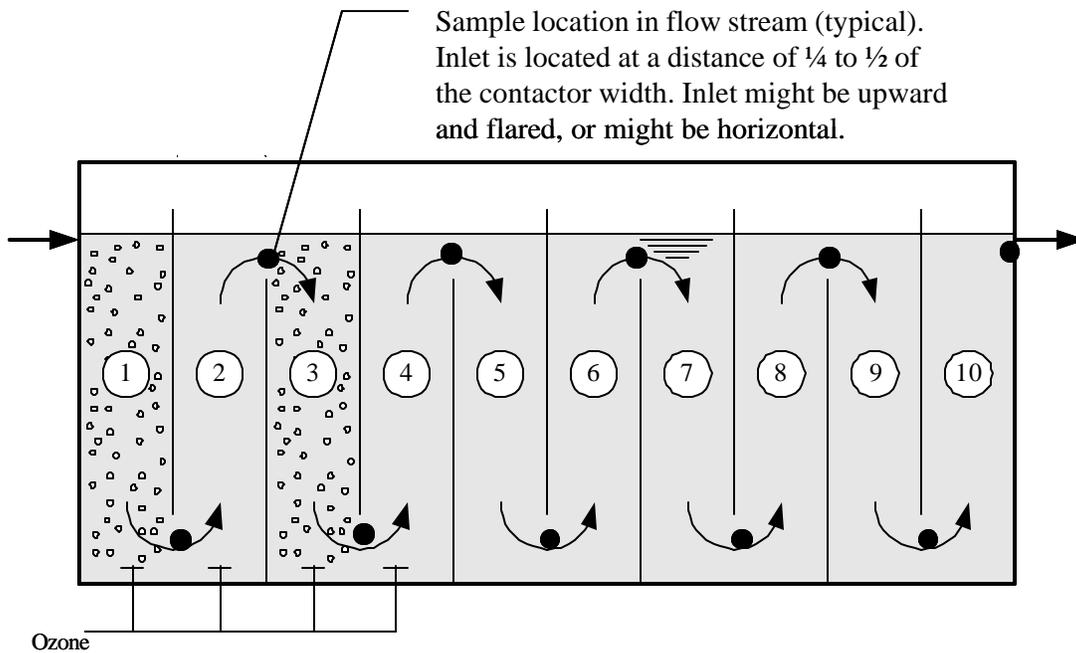
C.1 Sample Collection

The ozone residual in water decays rapidly. The half-life ranges from less than 1 minute to more than 20 minutes. Ozone contactors are sealed vessels with sample lines that penetrate the walls or roof structure of the contactor. The detention times in the sample lines should be as short as possible in order to minimize ozone residual decay (loss) in the sample lines.

The ozone residual profile in a contactor will vary significantly depending on the method of operation, water quality and water flow conditions (e.g., HDT). A separate sample port located at the outlet of each chamber within the contactor allows maximum flexibility for sampling ozone residual over variable operating conditions. Sample ports located at the outlets of diffusion chambers should be placed to ensure the diffusers do not interfere with the collected sample.

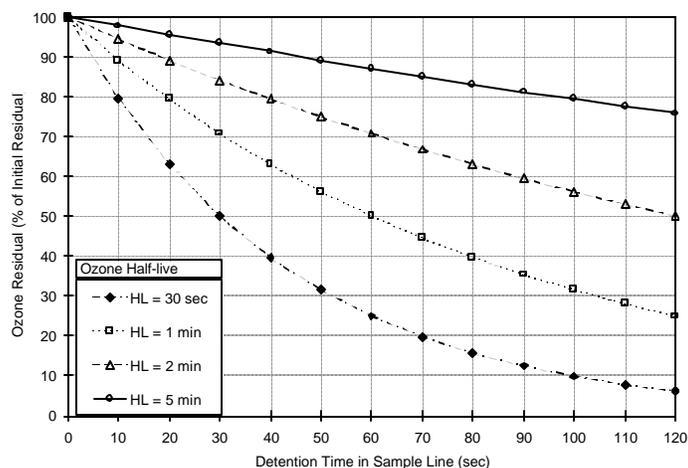
The inlet to the sample pipe inside the ozone contactor should be located directly in the main flow stream, such as shown in Figure C.1. The inlet should extend into the contactor sufficiently in order to obtain a representative sample (i.e. about $\frac{1}{4}$ to $\frac{1}{2}$ of the contactor width). Gas bubbles might be carried into the sample inlet and cause errors in the residual measurement. A sample inlet tube that is flared and that is turned either upward or opposite the flow of the water (depending on the location) reduces the potential for entrapment of gas bubbles. However in highly turbid waters, a vertical inlet and flared configuration might result in clogging due to solids deposition inside the line. In these cases a compromise is to position the sample line such that the inlet is horizontal rather than vertical.

Figure C.1 Example Sample Locations in an Over/Under Baffled Bubble Diffuser Contactor



Minimizing the travel time through the sample line is important, especially when the ozone decay rate is high (i.e., ozone half-life is short). It is desirable to minimize the travel time so that the ozone decay is <10 percent. Figure C.2 shows the relationship between simulated sample line travel time and ozone residual loss for various ozone half-life values. For example, the travel time in the sample line should be less than 10 seconds if the ozone half-life is one minute, in order to maintain the ozone residual loss at or below 10 percent.

Figure C.2 Relationship Between Ozone Residual Loss and Detention Time through the Ozone Sample Line for Various Ozone Half-Life Values



The sample line diameter should be large enough (minimum 3/8th inch inside diameter and preferably 1/2-in to 3/4-inch) to minimize clogging of the line with suspended solids. Sample pipe diameter and flow rate should be selected in order to:

1. Maintain consistent flow without plugging
2. Minimize detention time in the sample line
3. Meet flow rate requirements of an on-line analyzer installed at that location

Gravity flow is all that is necessary to meet sample flow requirements in most locations. In other cases, pumping is necessary. Sample lines might contain some gas bubbles as well as liquid. It is important to ensure that lines are vented in high spots where gas binding might occur. Gaseous ozone in high concentrations is hazardous to breathe. Sample line vents and drains should be directed away from occupied areas.

Some of these points are touched upon in Section O.3.2 of Appendix O of the SWTR Guidance Manual (1991).

C.2 Ozone Residual Measurement

Ozone residual is determined using the Indigo Method (Standard Methods 4500-Ozone – 20th Edition, 1998) when analyzing grab samples. The method assumes that high-purity reagents

are used. Since the publication of the 20th Edition, several reports (Gordon et al., 2000a and 2000b; Rakness et al., 2001; Rakness and Hunter, 2001; and Rakness et al., 2002) have been published discussing a potential biasing in the Indigo Method. The potential biasing involves the value of the so-called “sensitivity factor”, f , as defined in the Standard Method. In short, these reports suggest that the actual sensitivity factor might be lower than the Standard Method’s value, and hence the calculated ozone concentration will be undervalued.

The Standard method’s proportionality constant, f , ($0.42 \text{ L mg}^{-1} \text{ cm}^{-1}$) that is used to calculate the ozone residual is based on an indigo trisulfonate molar absorbance, e , of $20,000 \text{ M}^{-1} \text{ cm}^{-1}$. These recent reports suggest that f may not be constant and may depend on:

1. The source and age of the neat indigo trisulfonate solid
2. The age and handling of the indigo stock solution that is prepared as part of the method

Briefly, these reports indicate that, due to either of the above aspects, f can be substantially lower than $0.42 \text{ L mg}^{-1} \text{ cm}^{-1}$. In other words, the molar absorbance can be much lower than $20,000 \text{ M}^{-1} \text{ cm}^{-1}$. Gordon et al. (2000a and 2000b), Rakness et al. (2001), Rakness and Hunter (2001), and Rakness et al. (2002) reported that the apparent molar absorbance of some indigo stock solutions might be as low as $11,000 \text{ M}^{-1} \text{ cm}^{-1}$, and in an extreme case $6,000 \text{ M}^{-1} \text{ cm}^{-1}$. The authors suggest that the ramifications of applying an f value of $0.42 \text{ L mg}^{-1} \text{ cm}^{-1}$ when the solution has a lower true f value are the underestimation of the ozone concentration.

These issues are not completely resolved at the time of the writing of this guidance manual. However, the evidence is suggestive enough to warrant a new recommended QA control concerning the quality of the indigo stock solution. Should changes in the Standard Method be approved prior to issuing the final version of this guidance, those changes will be discussed.

The gravimetric indigo trisulfonate method is fairly easy to apply in the field and is accurate. It should be noted that the method described herein is somewhat different than the 20th Edition of Standard Methods in that the volume of both the blank and the samples are determined gravimetrically. The procedural steps include:

1. Prepare indigo stock solution as described in Standard Methods
2. Prepare Reagent II solution (for ozone residuals greater than 0.05 mg/L), as described in Standard Methods.
3. Prepare flasks for sampling.
 - 3.1. Clean, dry and label several 125 mL Erlenmeyer flasks (enough for each sample plus one blank).

- 3.2. Obtain the tare weight of each flask.
4. Add 10.0 mL of Reagent II solution to each flask.
5. Add approximately 90 mL of distilled water to one or two flasks and use these flasks as the blank (i.e., use value from one blank or average of values from two blanks).
6. Collect ozone sample.
 - 6.1. Thoroughly flush sample line to be used.
 - 6.2. Do not run sample down the side of the flask, as this will cause ozone off-gassing.
 - 6.3. Fill flask with sample, gently swirling flask until a light blue color remains. Do not bleach completely or the residual value will be incorrect.
7. Wipe-dry the outside of sample and blank flasks.
8. Weigh sample and blank flasks.
 - 8.1. Total weight for sample is tare weight of flask plus 10 mL indigo plus added sample.
 - 8.2. Total weight for blank is tare weight of flask plus 10 mL indigo plus added distilled water.
9. Prepare the spectrophotometer for measuring absorbance.
 - 9.1. Identify the cell path length (e.g., 1-cm, 5-cm, etc.).
 - 9.2. Set the wavelength to 600 nanometers.
10. Measure absorbance of blank and samples within four hours.
 - 10.1. Follow instructions for spectrophotometer concerning zeroing the instrument.
 - 10.2. Record absorbance of each sample and each blank.
11. Complete calculations – see example below.

Example:

A 10 mL aliquot of Reagent II solution was added to a 125 mL Erlenmeyer flask that was used for the blank. The flask had a tare weight of 83.62 g. The final weight of the flask, plus the 10 mL aliquot of reagent, plus the added distilled water was 179.77 g. The total volume of the 10 mL Reagent II aliquot plus added distilled water was determined by subtracting the bottle's tare weight from the total weight, assuming that 1 mL of liquid weighs 1 g ($96.15\text{-mL} = [179.77\text{-g} - 83.62\text{-g}] * 1\text{-mL} / 1\text{ g}$).

The spectrophotometer had a path length of 1 cm. The absorbance reading of the gravimetric blank was measured as 0.234 cm^{-1} at wavelength of 600 nm. This reading must be

corrected for the difference in the volume of the blank used in order to check the quality of the reagent. The calculated absorbance of a 1:100 blank dilution can be determined using Equation C-1. In this case, the 1:100-absorbance value was 0.225-cm^{-1} , which is greater than or equal to 0.225-cm^{-1} . This means that the indigo trisulfonate solution was considered acceptable.

$$\frac{\left(\frac{\text{Absorbance}}{\text{Path Length}}\right)}{100 \text{ mL}} \times \text{Volume of Blank} = \text{Absorbance in cm}^{-1} @ 100 \text{ mL} \quad (\text{C-1})$$

$$\frac{\left(\frac{0.234}{1 \text{ cm}}\right)}{100 \text{ mL}} \times 96.15 \text{ mL} = 0.225 \text{ cm}^{-1}$$

The 125-mL flask that was used for the ozone sample had a tare weight of 94.10 g. Sample water was directed into the 10-mL of Reagent II solution until a light blue color remained. The final weight of the flask, plus the 10-mL aliquot plus the sample, was 167.39 g. The absorbance reading at a path length of 1 cm was 0.159. The volume of the water sample was 63.29-mL ($63.29\text{-mL} = [167.39\text{-g} - 94.10\text{-g} - 10\text{-g}] * 1\text{-mL} / 1\text{-g}$). The ozone residual was calculated using Equation C-2, which resulted in a value of 0.41 mg/L.

$$\text{mg/L} = \frac{(A_B \times V_B) - (A_S \times V_T)}{f \times V_S \times b} \quad (\text{C-2})$$

where A_B = absorbance of the blank (as measured, not as corrected by equation C-1)

A_S = absorbance of the sample

V_B = volume of the blank plus indigo, mL

V_T = total volume of the sample plus indigo, mL

V_S = volume of the sample (total weight – tare weight – 10)

f = 0.42

b = path length of cell, cm

$$\frac{(0.234 \times 96.15) - (0.159 \times 73.29)}{0.42 \times 63.29 \times 1} = 0.41 \text{ mg/L}$$

C.3 On-line Ozone Residual Analyzer Calibration

On-line ozone residual analyzers are available that can continuously monitor ozone residual in the water. This makes it possible to automate the disinfection credit calculation using the plant's computer-control system. However, the analyzers must be maintained properly and their calibration must be checked periodically so that readings match grab-sample results that are based on the indigo trisulfonate procedure. Generally, probe-type monitor readings tend to drift downward over time due to weakening of the electrolyte solution. Calibration checks should be conducted regularly, such as at least once per week. This section describes a calibration check protocol which involves collecting grab-samples and analyzer readings simultaneously and comparing the values.

The calibration check should consist of collecting at least three, and preferably five, ozone residual grab samples and corresponding analyzer readings. The following calibration protocol has been used successfully at operating ozone facilities.

1. Collect three to five grab-sample ozone residuals. Obtain an analyzer reading while the grab sample is being collected. Wait 15 seconds to 30 seconds between each pair of grab sample and analyzer reading.
2. Measure the ozone residual concentration in the grab samples using the indigo trisulfonate method.
3. Calculate the average grab-sample ozone residual value and the average analyzer ozone residual value.
4. Compare the average of the on-line analyzer to that of the indigo grab-samples. The average of the on-line analyzer cannot deviate more than 10% or 0.05 mg/L (which ever is largest) from the grab-sample average. If the average of the on-line analyzer deviates more than this, then adjust the meter reading per the manufacturer's instructions. Note that this QA control is two-sided. It is especially important that the on-line analyzer not record more than 10% or 0.05 mg/L greater than the grab samples. However, a negative deviation (negative bias), while not effecting public safety, may also be useful as an indication of a malfunctioning unit.
5. Allow the analyzer to stabilize for a period of 30 minutes after adjusting the meter reading and repeat steps 1 through 4 until the difference calculated in step 4 is <10% of the grab-sample average and <0.05 mg/L.

Appendix D

Derivation of Extended CSTR Equations

The discussion presented in the document used some key equations and relied on specific assumptions. In this appendix, one key equation is derived, and one key assumption is discussed and justified.

D.1 Derivation of the Equation Used to Calculate k^*

In Appendix B, Equation B-2 expressed the value of k^* between two points 1 and 2 as shown by Equation D-1:

$$k_{1-2}^* = \frac{N_{1-2} \times Q}{[Volume]_{1-2}} \left[\left(\frac{C_1}{C_2} \right)^{\left(\frac{1}{N_{1-2}} \right)} - 1 \right] \quad (D-1)$$

Equation D-1 is a transformation from the equation of first-order decay across a series of N equal-size CSTRs:

$$\left(\frac{C_2}{C_1} \right) = \frac{1}{\left[1 + k_{1-2}^* \left(\frac{HDT}{N_{1-2}} \right) \right]^{N_{1-2}}} \quad (D-2)$$

The derivation of this equation can be found in many reference texts on modeling chemical reactors (e.g., Froment et al., 1990; Levenspiel, 1999). Since HDT is equal to the volume between locations 1 and 2, $[Volume]_{1-2}$, divided by the flowrate, Q , then Equation D-2 is transformed to Equation D-3:

$$\left(\frac{C_2}{C_1} \right) = \frac{1}{\left[1 + k_{1-2}^* \left(\frac{[Volume]_{1-2}}{Q \times N_{1-2}} \right) \right]^{N_{1-2}}} \quad (D-3)$$

Therefore,

$$\left[1 + k_{1-2}^* \left(\frac{[Volume]_{1-2}}{Q \times N_{1-2}} \right) \right]^{N_{1-2}} = \left(\frac{C_1}{C_2} \right) \quad (D-4)$$

then,

$$\left[1 + k_{1-2}^* \left(\frac{[Volume]_{1-2}}{Q \times N_{1-2}} \right) \right] = \left(\frac{C_1}{C_2} \right)^{\frac{1}{N_{1-2}}} \quad (D-5)$$

then,

$$k_{1-2}^* \left(\frac{[Volume]_{1-2}}{Q \times N_{1-2}} \right) = \left[\left(\frac{C_1}{C_2} \right)^{\frac{1}{N_{1-2}}} - 1 \right] \quad (D-6)$$

and then,

$$k_{1-2}^* = \frac{Q \times N_{1-2}}{[Volume]_{1-2}} \left[\left(\frac{C_1}{C_2} \right)^{\frac{1}{N_{1-2}}} - 1 \right] \quad (D-7)$$

As noted, Equation D-2 is based on the fundamental assumption that the hydrodynamic profile through the volume separating locations 1 and 2 can be approximated by a series of N equal-size CSTRs. If equal-size chambers separate locations 1 and 2, then each chamber is somewhat conservatively assumed to be an ideal CSTR, with $HDT = [Volume]/Q$, and the value of N in the above derivation is set equal to the number of chambers between locations 1 and 2. However, it was recognized that not all ozone contactors are configured with equal-size chambers in series. It is possible to treat each chamber as its own CSTR and have a series of unequal-size CSTRs. An expression of C_2/C_1 similar to that shown in Equation D-2 is still possible. For example, if locations 1 and 2 were separated by three CSTRs with HDT values of HDT_a , HDT_b , and HDT_c , the ratio of C_2/C_1 for a first-order decay reaction can still be expressed as:

$$\left(\frac{C_2}{C_1} \right) = \frac{1}{[1 + k_{1-2}^*(HDT_a)]} \times \frac{1}{[1 + k_{1-2}^*(HDT_b)]} \times \frac{1}{[1 + k_{1-2}^*(HDT_c)]} \quad (D-8)$$

Or in general terms,

$$\left(\frac{C_2}{C_1} \right) = \prod_i \frac{1}{[1 + k^*(HDT)_i]} \quad (D-9)$$

Unfortunately, it is not possible transform Equation D-9 to derive a simple linear expression of k^* as a function of the other measured parameters when the number of chambers is greater than three. To maintain a singular methodology for any number of chambers, and to allow the calculation to be performed in conventional spreadsheets and plant computer control systems, a compromise was to assume equal-volume CSTRs. With this assumption, Equation D-1 is used to calculate the value of k^* between two sampling locations regardless of the number and sizes of chambers between the two locations.

The simplifying assumption of equal-size CSTRs for calculating k^* is non-conservative relative to a k^* value calculated by allowing for unequal sized chambers. That is, for first-order ozone decay reaction, unequal sized CSTR reactors in series would be the least efficient (ideal) reactor configuration for promoting ozone decay. Hence, calculating k^* based on equation D-9 gives the largest, or most conservative, value of k^* . The model of equal sized CSTR reactors in series is a more efficient configuration for promoting ozone decay. Hence, calculating k^* from Equation D-1 (based on equation D-2) gives a less conservative estimate of k^* . To take the comparison to the opposite extreme, calculating k^* based on a plug-flow assumption (e.g., Equation 4-7) gives the smallest, or a non-conservative, estimate of k^* .

The impact of the simplifying equal-sized CSTR assumption on the estimate of k^* and C_{in} involves several considerations. The first issue is the quantitative difference between the most conservative estimate, based on Equation D-9, and the recommended approach based on Equation D-2. This is essentially an issue of what chemical and hydrodynamic conditions affect the efficiency of the ozone decay reaction. This is a somewhat complex issue dependent on the reaction rate (represented by the Damkohler I Number, D_{a1} [$D_{a1} = k^* \times \text{HDT}$]), the number of chambers considered, and the disparity in volumes among the unequal-sized chambers. In principal, as the reaction rate increases, the number of chambers approaches two (the minimum), and the volume differences among the chambers increases, the difference in reaction efficiency between the two reactor configurations increases. Some situations could result in approximately 30% differences between k^* values. Other situations could result in negligible differences. Because of the many factors involved it is difficult to establish qualitative rules for all possible cases. However, for contactors with 2-3 chambers with a large volume difference and a large D_{a1} , then the utility and the primacy agency may consider further analysis.

The second, and perhaps overriding, issue concerning the impact of the simplifying assumption is whether or not it still provides a certain element of conservatism over the true contactor performance. That is, an actual contactor with unequal sized chambers might have reasonably good hydrodynamics such that even the equal-size CSTR assumption is conservative. This too, however, is very system specific, and is a difficult issue to resolve due to the numerous factors involved.

Appendix E

Watershed Control Best Management Practices (BMPs)

This appendix provides a list of programmatic resources and guidance available to assist systems in building partnerships and implementing watershed protection activities. Examples of partnerships and possible control measures for different sources are summarized in chapter 2, section 2.4.2; this appendix provides further detail to the control measures described in chapter 2.

E.1 Regulatory and Other Management Strategies

For systems in watersheds where most of the land is privately owned, land use regulations may be the best way to control pollution, especially in heavily developed or growing areas. Examples of possible regulations include septic system requirements, zoning ordinances specifying minimum lot sizes or low-impact development, limits on discharge from wastewater treatment plants and other facilities, pet waste cleanup ordinances, and requirements for permits for certain land uses. Your ability to regulate land use will depend on the authority granted to your municipality by the state, the ownership of your system (public or private), and the support of your local government and the public. Regulatory authority, steps for designing a regulation that can withstand lawsuits, and types of land use regulations are described in the paragraphs below.

E.1.1 Determining Authority to Regulate

Where a water system is privately owned, it may be necessary to ask the cooperation of the local government to get source water regulations passed. For a municipal water system whose watershed is located entirely within the municipality, issuing zoning or land use ordinances should be less of a hurdle. The ability of a municipality to pass a land use ordinance or other law to help reduce contamination may depend on the authority the state grants to the local government in the state constitution or through legislation, although states normally do not interfere with the actual land use and zoning rules (AWWARF 1991). States generally permit zoning for the purposes of protecting public health or general welfare. However, some states may prevent local governments from passing laws that are more stringent than state law or that conflict with state laws. State laws in other states may prevent municipal governments from passing certain local laws that are not expressly permitted elsewhere in state law.

If the watershed or the area of influence on water quality extends throughout several municipalities, it can be difficult to standardize watershed control practices throughout the watershed. The legal framework used will depend on who has jurisdiction over land use in the watershed and on the authority of the water system (AWWARF 1991). New York State law, for instance, authorizes municipalities to draft watershed regulations, which are then approved and adopted by the state. This gives the municipalities the authority to enforce the watershed rules within their watersheds even if the

watershed is outside municipal boundaries. For instance, New York City sets water quality standards, land use restrictions, and approves wastewater treatment plant designs in its watersheds in upstate New York. The City of Syracuse conducts watershed inspections on Skaneateles Lake, its source of supply, several miles outside of Syracuse. Both of these systems are filtration avoidance systems, so it is especially important that they have some control over areas outside their jurisdictions.

The Metropolitan District Commission, although not a PWS, was created by the State of Massachusetts and is authorized to promulgate and enforce watershed protection regulations in watersheds used by the Massachusetts Water Resources Authority to provide water to the Boston metropolitan area. Some watersheds which extend across state boundaries have governing bodies authorized by Congress. The formation of the Tahoe Regional Planning Agency was the result of a compact between the States of California and Nevada and was approved by Congress. The agency is authorized to pass ordinances, including source water protection rules, that regulate land use in the area around Lake Tahoe.

County governments in some states may have some zoning authority and may be able to assist with enforcement of some regulations affecting source water (e.g., septic systems). In most cases where watersheds cross jurisdictions, however, PWSs will not have regulatory or enforcement authority. PWSs in this situation should work with other local governments' PWSs and agencies in their watersheds to sign memoranda of agreement or understanding, in which each entity agrees to meet certain standards or implement certain practices.

The City of New York signed a memorandum of agreement in 1997 with the State of New York, EPA, and 79 municipalities within its watersheds. The agreement calls for the creation of local and regional watershed protection programs and, for New York City, funding for water quality and infrastructure improvement projects in upstate New York. Other cities, such as Salem and The Dalles, both in Oregon, have signed memoranda of understanding with the U.S. Forest Service, which owns most of the land in the cities' watersheds. These memoranda define the management responsibilities of each PWS and the Forest Service.

E.1.2 Zoning

This section describes the steps you should follow to make sure a zoning law can withstand a legal challenge. Basically, it is important to make sure the appropriate procedures are followed and that the law has sufficient scientific basis (AWWA 1999). First, be sure you have the authority to regulate, especially if you are proposing something besides a simple zoning law. Make sure the rule is specific enough; if a map of an overlay district is not drawn to a small enough scale, it may be difficult to tell which properties are affected. Comply with all administrative procedure requirements, such as notifying the public of the proposed changes and holding a public hearing; failure to do so is the most common reason for rules being revoked. Follow substantive due process, which means that the regulation

should promote the municipality's public health goals. In practice, this means the ordinance should conform to the objectives of the watershed control program plan. The plan should contain enough data to illustrate how the ordinance will affect water quality.

Ordinances should also be designed to withstand a takings lawsuit (AWWA 1999). The fifth amendment to the U.S. Constitution states that private property may not be taken for public use without just compensation. Any physical invasion without consent is always considered a taking, even if the landowner retains ownership of the land. Installation of a monitoring well or stream gauge without consent is an example of a taking.

In addition, ordinances that "fail to advance a legitimate government interest" or "deny a landowner economically viable use of his land" can be viewed as takings, even if the landowner retains full ownership (AWWA 1999). The first criterion means that there should be a need for the ordinance; for example, if a planned development's storm sewers and wastewater treatment plant will discharge into an area outside a municipality's wellhead protection area, the municipality cannot cite impacts on the drinking water as a factor in the decision to restrict development without compensating landowners. Under the second criterion, if property values decrease but still retain some value (e.g., due to a decrease in permitted building density), the ordinance does not result in a taking. A regulation that restricts all development would probably be considered a taking. In keeping with these two criteria, the effect of an ordinance should be proportional to the predicted impact of development. Thus, if a municipality determines that half-acre zoning is sufficient to protect a drinking water source, it may not zone for five acres.

To prevent takings claims, the municipality should show the need for the regulation and a connection between the ordinance and the expected result (AWWA 1999). This proof should be based on a scientific analysis beginning with an accurate delineation of the watershed or wellhead protection area/recharge area. A zoning district based on an arbitrary fixed radius around a well or lake would probably be considered insufficient in court unless it is characterized as an interim boundary. A court challenge could claim that such a district protects an area that does not contribute to the watershed *or* that land that is part of the watershed is not being protected (failing to advance the government's interests).

Following the delineation, determine the impact the regulation will have by mapping current and projected residential, commercial, and industrial development under current zoning requirements. Then map current and projected development for existing regulations and for the proposed ordinance, and determine the potential pollutant load under each scenario (AWWA 1999). You may not be able to determine *Cryptosporidium* loading if you have not monitored, but there may be data available on fecal coliform bacteria from different sources in your watershed (e.g., agriculture, septic system failure, pets and wildlife). If your PWS has not collected such data, other local agencies, such as sewer authorities, non-profit groups, universities, or planning commissions, as well as the U.S. Geological Survey, may have water quality data. Water quality models can help you determine pollutant loading.

This “buildout analysis” will help you show how your proposed ordinance advances a legitimate government interest and how the effect of the ordinance is proportional to the impact of land use in your watershed.

Types of Ordinances

Watershed ordinances usually apply within an “overlay district,” which may be the area of influence you determined for your watershed control plan. All existing zoning or land use regulations apply within that area, but additional requirements apply within the overlay district. Following are some land use ordinances you may wish to consider:

- Large-lot or low-density zoning. Unless lots are very large (such lots can use septic systems and wells), large-lot zoning may be inefficient, as it increases costs for sewer, water, and road development. This type of zoning also may go against affordable housing requirements. However, it may be useful in agricultural areas for preserving rural character and preventing subdivision of farms.
- Limits on certain types of land use except by special permit. Such ordinances should specify criteria for granting special permits and designate an authority that may grant permits. The authority should present findings that back up its decision to grant the permit. Special permits are granted for a particular lot, not for the owner of that lot.
- Impact fees. The regulating authority must be sure it has authority to impose such fees. Impact fees collected can be used to pay for mitigation of pollution caused by development, e.g., for preventing runoff or buying land elsewhere in the watershed. Fees should be proportional to the impact and the cost of mitigation, and the purpose of the fees should be specified in the regulation. A disadvantage to impact fees is that they may in some cases be considered taxes, and local governments’ authority to impose taxes may be limited. Fees are more likely to withstand challenge if they are framed as optional services provided to the developer (i.e., the developer can choose not to develop) and if the fees are set aside for the PWS or stormwater utility rather than put into general funds.
- Submission and approval of a watershed protection plan or impact study as a condition for development of a subdivision or apartment complex. This type of ordinance requires that watershed protection plan or stormwater control be implemented before a building certificate of compliance is issued. Plans should be required to designate the party responsible for maintaining stormwater facilities after construction is complete.
- Performance standards. A performance standard permits development but limits impact of the development. For example, the regulation could specify that permits require that the pollutant loading rate of the development is no more than a certain percentage of the pre-

development loading rate of the area. This would require enforcement or monitoring to make sure the development continues to comply. In its permit application, the developer would also be required to list mitigation steps it would take if it exceeded the pollutant loading requirements.

Most zoning ordinances have grandfather clauses that allow nonconforming land uses to continue. Ordinances may also allow the zoning authority to grant variances if the topography or size of a lot make it difficult to comply with a zoning requirement.

Examples of source water protection ordinances can be found at <http://www.epa.gov/owow/nps/ordinance/osm7.htm>.

E.1.3 Land Acquisition and Conservation Easements

Acquisition of watershed land by the utility or its affiliated jurisdiction is often the most effective approach to protecting the water source. Landowners usually consider acquisition as fair, since it compensates them for their property while protecting the watercourses nearby. Land conservation has also been found to provide multiple benefits aside from controlling pathogen contamination, such as flood control, limited recreational use, and the protection of historic and environmental resources. EPA's Drinking Water State Revolving Fund allows a percentage of the fund to be set aside for land acquisition associated with watershed protection.

Several organizations exist that can help systems purchase watershed land to protect drinking water quality, especially when government agencies are unable to move quickly enough to buy land when it becomes available. The Trust for Public Land (<http://www.tpl.org>) and small local land trusts and conservancies can facilitate the land acquisition process. Trusts can buy and hold land from multiple landowners on behalf of a water system until the system can assemble funding to purchase it from the trust. Trusts may also maintain land ownership themselves. The Trust for Public Land also can assist with development of financing strategies for land purchases.

Trusts also can work with landowners to buy or have landowners donate conservation easements. An easement is a legal document that permanently limits the development of a piece of land, even after the land is sold or otherwise changes ownership. The landowner selling or donating the easement specifies the development restrictions to apply to the land. The law varies from state to state, but the owner of the easement (the government agency or land trust) has the authority to determine if the requirements of the easement are being followed. If not, the owner of the easement make take legal action. Easements donated to government agencies or to land trusts may be eligible for tax deductions. See <http://www.landtrust.org/ProtectingLand/EasementInfo.htm> for frequently asked questions about easements and for an example of a model easement for use in the State of Michigan. The Land Trust

Alliance (<http://www.lta.org>), a trade organization for land trusts, has published handbooks on designing and managing conservation easement programs.

Other government agencies, such as the U.S. Forest Service or state natural resource departments, may be able to buy parcels in your watershed if you are unable to afford to purchase all the land that needs to be protected.

E.2 Addressing Point Sources

E.2.1 Concentrated Animal Feeding Operations

Some animal feeding operations (AFOs) may be considered concentrated animal feeding operations (CAFOs) if they have more than a specified number of animals and/or if they discharge pollutants into navigable waters through a manmade ditch or other device or if they discharge directly into waters of the United States. Possible sources of pollutants at CAFOs include runoff that flows through feedlots; failure of pumps, pipes, or retaining walls of manure storage lagoons; runoff from areas where manure is applied to the soil; and direct contact of animals with surface water. CAFOs are located primarily in the South and Midwest, but the number of such facilities is increasing as farms consolidate their operations.

EPA recently issued a rule that changed the requirements on CAFOs that must apply for National (or State) Pollutant Discharge Elimination System (NPDES) permits (U.S. EPA 2003). All CAFOs are regulated as point sources in the NPDES program. Previously, CAFOs could be exempt from permitting if they could show that they did not discharge during 25-year 24-hour storms. The new rules eliminate this exemption, unless a facility can show that it does not discharge at all. NPDES permits for CAFOs generally allow zero discharge of pollutants and may also require the use of certain technologies. CAFOs are required to report to the state within 24 hours of exceeding effluent limits (U.S. EPA 2001a).

Many CAFOs do not currently have permits due to limited state resources for compliance (medium and small AFOs may be designated as CAFOs only by state or regional staff after onsite inspection). For CAFOs (and other NPDES permittees) that do have individual permits, you may want to attend the public hearing required as part of the permit renewal process, especially if you have any concerns about the adequacy of the existing permit requirements to prevent *Cryptosporidium* or other drinking water contamination. If a CAFO in your area of influence does not have a permit, consider encouraging its managers to apply for one or working with them to implement a nutrient management plan or other BMPs.

E.2.2 Wastewater Treatment Plants

All wastewater treatment plants in the United States are required to provide secondary treatment (primary treatment consists of sedimentation, while in secondary treatment, aeration provides oxygen to bacteria that take in nutrients and digest organic material) (U.S. EPA 2001b). Most plants are also required to disinfect their effluent before discharging. However, conventional chlorine disinfection may be ineffective against *Cryptosporidium*.

Some wastewater treatment facilities are beginning to implement treatment similar to that used for drinking water treatment. The Robbins Plant of the Upper Occoquan Sewerage Authority in Centreville, Virginia, discharges into a stream that feeds into a reservoir in northern Virginia. Following secondary treatment using activated sludge, the facility provides other treatment, including clarification, multimedia filtration, and disinfection (U.S. EPA 2000a). The Cole Pollution Control Plant in Fairfax County, Virginia, which discharges into a creek flowing into the Potomac River, also uses advanced treatment, including chlorine disinfection, filtration, and dechlorination (Fairfax County 2001).

PWSs should identify all wastewater treatment plants in their watersheds and determine what their permit effluent limits are and whether the limits are being met. Some of this information may already be available through the source water assessment program. PWSs may wish to work with the wastewater utilities and appropriate government agencies to get them to voluntarily upgrade the treatment provided. PWSs with the appropriate legal authority may wish to require wastewater plants to use certain technologies. An example might be switching from chlorine to ozone or ultraviolet radiation disinfection before discharging.

E.2.3 Combined Sewer Overflows

Combined sewer overflows (CSOs) are most common in older cities in the northeastern and midwestern United States and can be a significant contributor of *Cryptosporidium* to urban watersheds.

There are three major structural solutions to the problem of CSOs. The first is to separate combined sewers into sanitary and storm sewers, where sanitary sewers flow to the wastewater treatment plant and storm sewers release to surface water. This separation may cause the unwanted side effect of increasing overall contamination due to the fact that storm water is no longer being treated. For example, separating sewers resulted in only an estimated 45-percent reduction in fecal coliform removal in a bay in Boston (Metcalf and Eddy 1994, cited in U.S. EPA 1999c). Separating sewers is also very expensive and often impractical. The second option is to increase the capacity of the wastewater treatment plant so that it is able to treat combined sewage from most storms. The third, very expensive solution is to build aboveground open or covered retention basins or to construct underground storage facilities for combined sewage to hold the sewage until the storm has passed and

can be treated without overloading the plant. The Metropolitan Water Reclamation District in Cook County, Illinois, chose the third option, building 109 miles of tunnel up to 35 feet wide and several underground reservoirs underneath Chicago and its suburbs, with most funding from EPA (MWRD 1999). In addition to reducing CSOs, the tunnels eliminated flooding that had previously affected the area due to its flat topography. The project also eliminated the need for individual municipalities to implement their own CSO programs.

CSOs are not regulated directly under their own program, but EPA has a CSO control policy (U.S. EPA 1994) which encourages minor improvements to optimize CSO operation, and CSO management may be written into NPDES or SPDES permits. The CSO policy also encourages development of long term control plans for each CSO system; such plans would require significant construction, and few utilities have drafted or implemented them yet. Planned construction projects can be included as control measures in watershed control plans. PWSs should determine the extent of the CSO programs in place in municipalities within their watersheds. They may be able to work with other utilities to address overflow sites of particular concern. Many municipalities with CSOs made major structural changes to their systems in the 1980s and 1990s; current improvements are more likely to involve streamlining operation and management.

Many large cities have already addressed a significant portion of their CSOs, but there are additional smaller steps they can take to reduce the amount of sewage released during a wet weather event. These include maximizing in-line storage (storage available in the sewer pipes themselves) through regular inspection and removal of obstructions and sediment, installation and maintenance of flow regulators, upgrading pumping capacity (assuming the treatment plant can handle the increased volume); raising weirs at CSO outfalls; and installing computerized sensors to control flow during storms.

Additionally, reducing inflow (entry of storm water into the combined sewers) and infiltration (entry of storm water through cracks and manholes) is important. Inflow can be reduced by disconnecting roof drains and sump pumps from sewers, restricting flow into storm drains, and constructing storm water detention ponds and infiltration devices. If overflow events can be reduced, it may be possible to eliminate some outfalls. Some sewer systems also have installed some treatment of CSOs including disinfection and screening; this treatment may be required as part of a NPDES permit.

E.2.4 Sanitary Sewer Overflows

Sanitary sewer systems normally feed into wastewater treatment plants but can still cause water quality problems. Sanitary sewer overflows (SSOs) occur when untreated and mostly undiluted sewage backs up into basements, streets, and surface water. SSOs discharging to surface water are prohibited under the Clean Water Act. Insufficient maintenance and capacity and illegal connections are some of the primary causes of SSOs. Many sanitary sewers are subject to inflow and infiltration,

just as combined sewers are, caused by cracks in pipes or bad connections to service lines. They may receive water they were not designed to receive, such as storm water from roof drains that should be connected to storm sewers, or wastewater from new developments that did not exist when the wastewater treatment plant was designed. SSOs can be reduced by cleaning and maintaining the sewer system; reducing inflow and infiltration by repairing leaking or broken service lines; increasing sewer, pumping, and/or wastewater treatment plant capacity; and constructing storage for excess wastewater (U.S. EPA 2001c). EPA is proposing a rule that will require sewer systems to implement capacity assurance, management, operation, and maintenance programs and will require public notification of overflow events. This information will assist PWSs in addressing SSO point sources.

E.2.5 Municipal Separate Storm Sewer Systems

Municipal separate storm sewer systems (MS4s) in areas with populations of more than 100,000 are also required to obtain NPDES permits. Information on storm sewer outfall locations, volume discharged, conventional pollutant loads, and existence of illicit discharges is submitted as part of the permit application process (U.S. EPA 1996). In addition, these MS4s must develop management plans addressing items such as outfall monitoring, structural and nonstructural BMPs to be implemented, and identification and elimination of illicit discharges. Illicit discharges to MS4s include any non-stormwater discharges, such as discharges that should be connected to sanitary sewers (e.g., water from sinks, floor drains, and occasionally toilets), illegal dumping of sewage from recreational vehicles, sanitary sewer overflow backing up through manhole covers into storm drains, effluent from failing septic systems, water from sump pumps, etc.

Small MS4s (serving areas with populations of less than 100,000) are subject to NPDES permit requirements if they are located in “urbanized areas” as determined by the Bureau of the Census. Some small MS4s in urbanized areas may be eligible for waivers from the NPDES requirement. Those MS4s subject to NPDES permits must implement “control measures” in six areas, including a plan for eliminating illicit discharges (U.S. EPA 2000b).

PWSs should work with all MS4 utilities in the area of influence to gather existing information about storm water contamination. MS4 utilities may need to install or retrofit structural BMPs, such as retention ponds, to reduce contamination. Most studies of structural stormwater BMPs focus on nutrient or sediment removal, so almost no information is available on *Cryptosporidium* removal, and limited information is available on bacterial removal. However, a few studies of bacteria in structural BMPs show that bacteria survive for weeks to months in retention pond sediments and natural lake environments. In addition, other studies showed higher bacteria levels in retention pond effluent than in influent. This suggests that stormwater pond sediments resuspended during storms can be a source of pathogens (Schueler 1999).

E.3 What BMPs Can Help Alleviate Nonpoint Sources?

The following sections describe BMPs for agricultural, forestry, and urban sources of *Cryptosporidium*. Your watershed control program plan must discuss how these or any other BMPs you choose will be implemented in the area of influence. EPA Section 319 grants and Clean Water State Revolving Fund loans can be used for nonpoint sources and watershed management purposes.

E.3.1 Agricultural BMPs

E.3.1.1 Management Programs

The U.S. Department of Agriculture (USDA) (2000) recommends a multiple-barrier approach to controlling pathogen transport and proliferation on farms and in agricultural watersheds. It recommends the following “control points:”

- Preventing initial infection by controlling pathogen import to the farm
- Controlling the reproduction and spread of the pathogen throughout the farm
- Managing waste
- Controlling pathogen export from the farm

These control points should not be treated separately. For example, waste management affects reproduction and spread of the pathogen if feed becomes contaminated with waste. Waste management is also related to pathogen export; composting can kill *Cryptosporidium* oocysts before they leave the farm.

BMPs that can reduce pathogen loading include composting, waste management (manure storage and land application), grazing management, feedlot runoff diversion, and buffer or filter strips. PWSs should work with their local soil and water conservation districts and agricultural or cooperative extensions, which can help farmers design and implement pollution management plans and BMPs. Details about these conservation practices are provided in the USDA Natural Resources Conservation Service’s (NRCS) National Handbook of Conservation Practices (NRCS 1999) at http://www.ftw.nrcs.usda.gov/nhcp_2.html.

Management strategies designed to minimize direct livestock contamination of surface water with *Cryptosporidium* should focus primarily on young animals (those less than 3 months old) and their waste, since calves are more likely to shed *Cryptosporidium*. Efforts should also focus on cow herds as a whole when calves are present.

Several NRCS programs provide technical assistance to farmers and subsidize the cost of implementing BMPs. These include Agricultural Management Assistance, the Environmental Quality Incentives Program, the Conservation Reserve Program, and the Conservation Reserve Enhancement

Program (see www.nrcs.usda.gov/programs). The last two programs also pay farmers rent on erodible cropland taken out of production. More information is available at <http://www.fsa.usda.gov/dafp/cepd/crpinfo.htm>. The 2002 Farm Bill increased funding for these programs and created new ones as well. For example, the new Conservation Security Program will recognize and reward farmers who are leaders in environmental management.

E.3.1.2 Composting

Composting can effectively reduce pathogen concentrations. Temperatures greater than 55 degrees Celsius (131° F) can be easily attained and maintained long enough to inactivate most oocysts (Blewett 1989). To reliably achieve *Cryptosporidium* inactivation, however, the entire waste mass should be uniformly treated and there should be no cold spots. Intense management may be needed to completely mix the composted material.

E.3.1.3 Buffer Strips

Buffer strips, or filter strips, provide a buffer between the area of manure application or grazing and adjacent streams or lakes. Filter strips have been studied primarily with regard to their effectiveness at sediment and nutrient removal. Nutrient removal has been shown to be extremely variable, while agricultural grass filter strips consistently remove 65 percent or more of sediment (Ohio State University Extension undated). How sediment removal relates to *Cryptosporidium* removal is not known. *Cryptosporidium* often adsorbs to suspended material the size of clay and silt particles, which is the type of sediment that is likely to pass through the filter strip, especially at high flow velocities.

Few studies have evaluated the ability of buffer strips to remove *Cryptosporidium*. However, one study found that grass filter strips with slopes of 20 percent or less and widths of at least 3 meters resulted in removal of 1 to 3 log (90 to 99.9 percent) during mild to moderate precipitation (Atwill et al. 2002). More data are available on removal of bacteria. Moore et al. (1988) reviewed the work of several investigators and concluded that vegetative filters are most reliable at removing bacteria at high concentrations from waste effluent. Bacterial populations in runoff from buffer areas seem to equilibrate at approximately 10⁴ to 10⁵ organisms per 100 milliliters, regardless of experimental conditions. For this reason, USDA (2000) recommends that buffers and filter strips be considered secondary practices for pathogen control and be used in conjunction with other source, proliferation, and waste treatment and control measures to form an integrated, comprehensive pathogen management system.

The NRCS encourages the use of riparian forest buffers of at least 35 to 100 feet (depending on floodplain width) for stream restoration purposes but recommends additional width in high sediment and animal waste application areas. Grass filter strips may be added upgradient of the forest buffers or may be used alone. The NRCS (1999) recommends grass filter strip widths of at least 20 feet, but width should be determined based on the slopes of the strip and the field being drained, the area being

drained, the erosion rate, sediment grain size distribution, runoff volume, and the vegetation in the strip. Filter strips should follow contours as much as possible to promote sheet flow. The area being drained should have a slope of less than 10 percent. Grazing should not generally be permitted within the filter strip. Maintenance activities should include mowing to prevent woody growth, inspection after storm events, repair of any gullies, reseeding of disturbed areas, and any other steps needed to maintain overland sheet flow.

E.3.1.4 Grazing Management

Managed grazing can be cheaper and less environmentally damaging than confined feeding and unmanaged grazing. It decreases feed, herbicide, equipment, and fertilizer costs, while reducing erosion and increasing runoff infiltration and manure decomposition rates (Ohio State University Extension, undated). In managed, or rotational, grazing, a sustainable number of cattle or other livestock graze for a limited time (usually 2-3 days) on each pasture before being rotated to the next pasture. This allows vegetation regrowth and prevents overgrazing, which can contribute to erosion and runoff, and helps distribute manure evenly over the grazed area. It also prevents soil compaction, thereby increasing infiltration. One of the best ways to prevent surface water contamination during rotational grazing is to prevent grazing along streams (through fencing and use of a buffer strip) and to provide alternative water sources for livestock. Providing water in each paddock can increase the number of cattle the pasture is able to support. Even where rotational grazing is not used, surface water contamination can be reduced by keeping cattle, especially calves, out of streams.

E.3.1.5 Manure Storage

Manure storage facilities allow farmers to wait until field conditions are more suitable for land application. Without manure storage facilities, farmers must distribute manure on adjacent fields daily. However, weather conditions are not always appropriate for manure application. During the winter, for example, frozen soil conditions allow *Cryptosporidium* oocysts to be washed into watercourses, and oocysts survive longer at cold temperatures.

Manure storage facilities should be designed to prevent discharge through leaching or runoff. They should be lined and, if possible, covered. Facilities that are not covered should be designed to contain precipitation and runoff from a 25-year 24-hour storm. Storage areas should have embankments to prevent overflow and collapse of the storage facility and to divert runoff from outside the facility from contamination. Facilities should be sited outside of flood plains. Manure should be stored for a time period sufficient for microorganisms to die off.

E.3.1.6 Land Application of Manure

Several precautions taken in manure application can prevent runoff from entering surface water, reducing the likelihood of *Cryptosporidium* contamination. Buffer strips should be situated between

the water body and area of manure application. Manure should not be applied to frozen ground or before predicted rainfall. Manure should not be applied near tile drains or dry wells or to land subject to flooding. If soil is dry and cracked, fields should be tilled before application. Soil and manure should be tested for nutrient levels, and the application rate should be tailored to the soil and specific crop needs. To minimize runoff, waste should be injected (injection creates holes 6-14 inches deep and does not turn soil over) or applied to the surface and then plowed under. Applying manure to land with crop residue or new crops rather than bare soil also minimizes erosion. Surface application without plowing under may be acceptable if conditions are warm and dry—this enables significant pathogen die-off (Vendrall et al. 1997) by exposure to UV light and desiccation. The Agricultural Waste Management Field Handbook (NRCS 1992), Chapter 5, Table 5-3 contains a detailed review of restricting features that should be considered during manure spreading.

For pastures to be used for grazing, waste should be stored for at least 60 days and then applied at least 30 days before the scheduled grazing period, to avoid infection of the animals. Use of these areas for grazing should be limited to mature animals. Manure spreading on pastures used for grazing or on hayfields should take place when minimal amounts of vegetation are present, just after harvesting or grazing. This allows sunlight and desiccation to destroy the most pathogens and reduces the chance of pathogen adherence to the forage.

Critical source areas are defined as saturated areas that can expand and contract rapidly, based on soil, hydrological, and slope characteristics (Gburek and Poinke 1995). These areas are dominated by saturated overland flow and rapidly respond to subsurface flow. Therefore, watershed managers should identify the boundaries of potential saturated areas and ensure that waste is only applied outside of those boundaries to minimize *Cryptosporidium* oocyst runoff. Some tools have been developed to delineate critical source areas (e.g., Cornell Soil Moisture Routing Model; Frankenberger 1999). Less detailed delineations can also be made using information such as soil drainage class, flooding frequency, wetland mapping, areas of concentrated flow, and aerial photo interpretations.

E.3.1.7 Feedlot Runoff Diversion

Clean roof and surface water can be diverted away from feedlots to a drainage system that is independent of a farm's waste management system (Ohio State University Extension 1992). All roofs that could contribute to feedlot runoff should have gutters, downspouts, and outlets that discharge away from the feedlot. Berms around the feedlot can divert surface runoff. Diverting clean water before it drains into the feedlot can significantly reduce the amount of wastewater that needs to be managed. Runoff within the feedlot should be contained and treated in the waste management system for the lot.

E.3.2 Forestry BMPs

Forestry practices are not likely to significantly contribute to *Cryptosporidium* sources, since wildlife levels decrease or, at most, remain constant after logging. However, logging can cause increased erosion, leading to increased runoff and making it more likely that *Cryptosporidium* present in wildlife will reach the source water. In addition, logging can cause elevated sediment levels, resulting in high turbidity, which affects water treatment efficiency.

Filter strips, where ground cover is maintained around lakes, permanent and intermittent streams, and wetlands, help trap sediment. Filter strip width should increase with slope of the area being logged. Streamside or riparian management zones are intended to stabilize stream banks and maintain shade over streams to minimize water temperature fluctuations. Streamside management zones and filter strips often overlap, but limited logging is often permitted within streamside management zones (NRCS 1999).

Logging roads should be constructed to minimize runoff through proper grading and drainage. Road runoff should be diverted away from streams and prevented from channelizing. Loggers should minimize soil disturbance and compaction on skid trails, the trails used to drag logs to trucks for loading (U.S. EPA 2002a).

E.3.3 Urban/Suburban BMPs

See <http://www.epa.gov/owm/mtb/mtbfact.htm> for fact sheets on technologies and BMPs municipalities can use to reduce contamination from wastewater and stormwater.

E.3.3.1 Buffer Zones

For watersheds in urban areas, buffer zones help to protect development on the floodplain from being damaged when the water is high, as well as protect the stream from the effects of the development.

The utility, municipality, or cooperating jurisdictions may acquire land bordering the reservoir and/or its tributaries. Alternatively, buffers can be required by zoning ordinances, conservation easements, or subdivision regulations. Buffer zones can be fixed width or variable width. In a fixed-width zone, the buffer zone encompasses a certain distance from the stream bank or some other hydrological reference point (e.g., the high water mark of a stream). The widths of fixed buffer zones vary considerably among water sources, frequently ranging from 50 feet to 250 feet of buffer from the stream edge. Another form of buffer zone, the variable-width buffer, can vary in width depending on the hydrological sensitivity, stream size, and character of the land adjacent to the watercourse.

Considerations for developing local buffer requirements are the size and location of the stream, the nature of existing or potential development, and the financial and political feasibility of establishing

protected zones around the streams and reservoir of the watershed. Although buffer zones have been found to trap fecal waste (Coyné and Blevins 1995; Young et al. 1980), the extent to which they reduce *Cryptosporidium* loading is not well understood. For this reason, buffer zones should be used to augment, rather than replace, other watershed management practices to help protect overall source water quality.

Buffer zones should be routinely inspected to ensure that sources of contamination have not been introduced to the area and that the buffer is being maintained (e.g., that buffers are kept unmowed). Watershed managers should also be aware of storm sewers and culverts that may be draining into the waterways and bypassing the buffer zones altogether.

E.3.3.2 *Dry Detention Basins*

Dry detention basins temporarily store stormwater runoff and release the water slowly to allow for settling of particulates and the reduction of peak flows. These structures hold a certain amount of water from a storm and release the water through a controlled outlet over a specified time period based on design criteria. Most basins dry out completely between storm events. The major failure of these basins is that some are not designed or maintained properly, resulting in too slow a release of water to empty the basin before the next storm. If the basin remains partially full, only a portion of the design runoff volume from the next storm will be retained. With inadequate detention, pollutants are not removed from the runoff. Dry detention basins also risk the possibility of resuspension of pathogens from the basin sediments if hydraulic retention times are compromised by poor design or failure to keep the outlets open.

E.3.3.3 *Infiltration Devices*

Infiltration devices remove pathogens and particles by adsorption onto soil particles and filtration as the water moves through the soil to the ground water. Infiltration devices include infiltration basins, infiltration trenches, and dry wells (NALMS 2000). Properly designed devices can reproduce hydrological conditions that existed before urban development, and provide ground water recharge and control of peak storm water flows. In order for them to function effectively, infiltration devices must be used only where the soil is porous and can readily absorb storm water at an adequate rate. An advantage of infiltration devices over many other urban BMPs is that they provide significant ground water recharge in areas with a high percentage of impervious surface.

E.3.3.4 *Sand Filters*

Sand filters can be used to treat storm water runoff from large buildings and parking lots. As the name implies, storm water is filtered through beds of sand, which may be located above ground in self-contained beds, or can be installed underground in trenches or concrete boxes. Underground sand filters can be installed in urban settings where space is restricted and the filters are not visible.

Pathogens and particles are removed by filtering storm water through approximately 18 inches of sand. Above-ground filters may be preceded by grassed filter strips or swales to pre-treat the incoming storm water and prevent the sand filters from clogging.

Sand filters are often more expensive to construct than infiltration trenches (NALMS 2000). They do not provide a significant amount of storm water detention, and their ability to remove pathogens is limited. They require little maintenance; the sand surface should be raked and a few inches of dirty sand on the filter surface should be removed and replaced periodically, so that the filters do not clog.

E.3.3.5 Wet Retention Ponds

Wet retention ponds maintain a permanent pool of water that is augmented by storm water runoff. The ponds fill with storm water, which they slowly release over several days until the pond returns to its normal depth. Ponds can effectively reduce suspended particles and, presumably, some pathogens, by settling and biological decomposition. There is concern, however, that ponds attract wildlife that may contribute additional fecal pollution to the water, rather than reducing contamination. Bacteria may also survive in pond sediment.

Many people find wet ponds aesthetically pleasing, and welcome their use for storm water control. Some maintenance of the ponds is required in order for them to continue to function effectively and to avoid nuisance odors and insect problems. Wetland plants should be periodically harvested, and the pond inlets and outlets should be kept clear so that flow is not impeded. Wet ponds can be an appealing play area for children, so safety measures should also be taken to restrict access..

E.3.3.6 Constructed Wetlands

Constructed subsurface flow wetlands (where wetland plants are not submerged) can reduce *Cryptosporidium* and bacteria concentrations in wastewater (Thurston et al. 2001). Subsurface flow prevents the public from coming into contact with wastewater and prevents mosquitos problems. Wetlands may also be useful for treating storm water or other polluted water. However, the matrix material of a constructed subsurface flow wetland (gravel is often used) may provide an environment for bacterial growth, and animals living in the wetlands may contribute microbes to the effluent (Thurston et al. 2001). Animals are probably less significant than they would be in a free water surface wetland. The growth of bacteria in the wetland medium is both positive and negative—bacteria that help break down materials in wastewater are more plentiful, but fecal coliform also can survive in such environments. Constructed wetlands are relatively inexpensive often used on small scales to treat water at small facilities such as schools, apartment complexes, and parks (U.S. EPA 2000c).

E.3.3.7 *Runoff Diversion*

As with feedlot runoff diversion, structures can be installed in more urban settings to divert clean water flow before it reaches a contamination source. Structures that channel runoff away from contamination sources include stormwater conveyances such as swales, gutters, channels, drains, and sewers. Graded surfaces can also be used to re-direct sheet flow, and diversion dikes or berms can be installed to route sheet flow around areas that are being protected from runoff.

E.3.3.8 *Pet Waste Management*

Municipalities can implement pet waste management programs to encourage pet owners to properly collect and dispose of their animals' waste. Many communities have pet waste ordinances that require pet owners to clean up after their pets on public property or anywhere outside their own yards; however, compliance is limited, and enforcement is usually not a priority. In addition, most ordinances do not require pet owners to clean up pet waste in their own yards (this problem can usually be addressed, though only reactively, through nuisance or pet neglect laws). Some communities have ordinances that govern the cleanup process by requiring disposal of pet waste with regular trash, burial, or flushing it down the toilet. Enforcement of these ordinances with fines for noncompliance is probably the best way to increase compliance.

To increase public awareness about pet waste, you can distribute educational materials through emails, letters, public service announcements, and signs. Posting is the most common outreach strategy for managing pet waste. Pet waste stations containing waste receptacles for public use are another popular solution. Public works departments have also formed voluntary commitment and partnership programs with pet owners and local pet stores in the community to promote good pet waste management.

E.3.3.9 *Water Conservation*

Water conservation is usually presented as a practice that can help preserve the amount of water available for use, especially in times of drought. However, water conservation can also decrease the amount of wastewater and stormwater generated, thereby protecting the *quality* of the water supply (U.S. EPA 2002b). Use of low-flow toilets and showerheads, for example, can allow wastewater treatment plants to treat wastewater from more customers without having to increase capacity, reducing the occurrence of combined or sanitary sewer overflows. The reduced load on wastewater treatment plants can also decrease the need for rate increases. Reducing lawn watering decreases the amount of runoff entering storm sewers, combined sewers, and surface water.

E.3.3.10 Low Impact Development

Low impact development, or better site design, is a watershed practice that reduces pollutant loads, conserves natural areas, saves money, and increases property values (Center for Watershed Protection 1999). A fundamentally different approach to residential and commercial development, site design tries to reduce the amount of impervious cover, increase natural lands set aside for conservation, and use pervious areas for more effective stormwater treatment. Low impact development involves changing traditional practices for residential street and parking lot design, lot development, and conservation of natural areas. Some specific steps for better site design include the following (Center for Watershed Protection 1999):

- Design residential streets based on the minimum width needed to support travel lanes, on-street parking, and emergency and maintenance vehicle access. For example, a street with single family houses with driveways does not need two lanes for parking. Construct sidewalks on only one side of the street.
- Minimize the number of cul-de-sacs. Where cul-de-sacs are built, place landscaped islands to reduce their impervious cover.
- Advocate open space or cluster design subdivisions on smaller lots.
- Reduce imperviousness by promoting alternative driveway surfaces and shared driveways that connect two or more homes together. Reduce driveway length by allowing decreased front setbacks.
- Direct rooftop runoff to pervious areas such as yards, open channels, or vegetated areas rather than the roadway and stormwater sewers. Better yet, install open vegetated channels instead of storm sewers.
- Reduce the imperviousness and size of parking lots by minimizing stall dimensions, incorporating efficient parking lanes, and using pervious materials in the spillover parking areas where possible. Use lower parking ratios where possible (e.g., where mass transit is available and codes permit).
- Provide stormwater treatment for parking lot runoff using bioretention areas, filter strips, and/or other practices.
- Create a naturally vegetated buffer system along all perennial streams that encompasses critical environmental features such as the 100-year floodplain, steep slopes, and wetlands.
- Clearing and grading of forests and native vegetation at a site should be limited to the minimum amount needed to build lots, allow access, and provide fire protection. Specify a party legally responsible for maintaining the vegetated area.

Some aspects of low impact development may be prohibited outright under traditional zoning and development regulations, so low impact development practices may need to be codified. Where such practices remain voluntary or require exemptions from existing regulations, water systems should work with local planners to encourage the switch to better site design.

E.3.3.11 Septic Systems

Failing septic systems can be a major source of microbial contamination in a watershed. Poor placement of leachfields can feed partially treated waste directly into a drinking water source. Poorly constructed percolation systems may allow wastewater to escape before it has been properly treated. Failing systems can result in clogging and overflow of waste onto land or into surface water.

Most septic system regulations require construction permits and an inspection before the system begins operating, but few require any follow-up. Where failing systems are a serious problem or are close to a drinking water source, however, some municipalities have maintenance or inspection requirements. For example, the Portland (Maine) Water District requires permits for all septic systems within 200 feet of Sebago Lake, its primary source (U.S. EPA 1999a). These septic systems are subject to regular inspection and may face stricter design requirements than systems outside the boundary. Portland also has the authority to inspect systems within 1,000 feet of Sebago Lake tributaries. Similarly, the Onondaga County Water Authority in New York visually inspects every septic system in the water system annually. Every three years each septic system is subject to a dye tracer test. Enforcement cases are referred to the county health department (U.S. EPA 1999a).

Although water systems rarely have enforcement authority over septic systems, they should work closely with the local regulatory authority to ensure that septic system codes are being properly enforced and to strengthen codes where necessary. Utilities should also encourage residents with septic systems in the watershed to understand their systems and the proper maintenance that their systems require. Home*A*Syst programs run by many state cooperative extensions provide educational material and checklists for septic system owners about proper siting and maintenance. Utilities may also want to encourage residents to hook up to a sanitary sewer system where feasible. Clean Water State Revolving Fund loans, USDA Rural Utilities Service funds, and Department of Housing and Urban Development Community Development Block Grants are available for septic system rehabilitation or replacement. Individual homeowners may be eligible for some of these loans (U.S. EPA 1999b). Some of these funds may also be used to build centralized wastewater treatment.

E.3.3.12 Wildlife BMPs

Steps taken to prevent wildlife from contaminating source water vary with the source and type of wildlife. Some reservoirs and lakes employ boats with noisemakers to scare seagulls and geese away. Many systems with control of the land around their reservoirs place fences on the water's edge to keep out larger land animals and humans. To keep geese from feeding along the river bank just upstream from one of its intakes, the Philadelphia Water Department planted a riparian buffer and wildflower meadow and conducted a public education program to prevent people from feeding the geese (Philadelphia Water Department 2003).

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