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SIMULTANEOUS COMPLIANCE GUIDANCE MANUAL FOR THE LONG TERM 2 AND STAGE 2 DBP RULES

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Purpose:

The purpose of this guidance manual is to provide technical information for water systems and states to assist them with complying with the Stage 2 Disinfectant and Disinfection Byproducts Rule, the Long Term 2 Enhanced Surface Water Treatment Rule, and other Safe Drinking Water Act (SDWA) regulations. This guidance is not a substitute for applicable legal requirements, nor is it a regulation itself. Thus, it does not impose legally binding requirements on any party, including EPA, states, or the regulated community. Interested parties are free to raise questions and objections to the guidance and the appropriateness of its use in a particular situation. Although this manual describes many methods for complying with SDWA requirements, the guidance presented here may not be appropriate for all situations, and alternative approaches may provide satisfactory performance. The mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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List of Abbreviations and Acronyms

AOC	assimilable organic carbon
APHA	American Public Health Association
AMTA	American Membrane Technology Association
As(III)	arsenite
As(V)	arsenate
AWWA	American Water Works Association
AwwaRF	American Water Works Association Research Foundation
BAT	best available technology
BLS	below land surface
BMPs	best management practices
BDOC	biodegradable dissolved organic carbon
C	disinfectant concentration in mg/L (in CT calculations)
CDPHE	Colorado Department of Health and Environment
CFE	combined filter effluent
CIS	Customer Information System
CO_2	carbon dioxide
$CaCO_3$	calcium carbonate
CPE	comprehensive performance evaluation
CT	disinfectant concentration x contact time, a measure of disinfection performance
CTA	comprehensive technical assistance
CWS	community water system
DBP	disinfection byproduct
DBPR	Disinfectants and Disinfection Byproducts Rule
DCWASA	Washington D.C. Water and Sewage Authority
DE	diatomaceous earth
DO	dissolved oxygen
DIC	dissolved inorganic carbon
DOC	dissolved organic carbon
DOP	demonstration of performance
EBCT	empty bed contact time
EPA	U.S. Environmental Protection Agency
FBRR	Filter Backwash Recycling Rule
GAC	granular activated carbon
GPM	gallons per minute
GWR	Ground Water Rule
GWUDI	ground water under the direct influence of surface water
H_2CO_3	carbonic acid
HCO_3^-	bicarbonate
HAA	haloacetic acid
HAA5	the sum of five HAA species (monochloroacetic, dichloroacetic, trichloroacetic, monobromoacetic, and

	dibromoacetic acids)
HACCP	Hazard Analysis and Critical Control Point
HOCl	hypochlorous acid
HPC	heterotrophic plate count
HRT	hydraulic residence time
ICR	Information Collection Rule
ISO	International Organization for Standardization
IESWTR	Interim Enhanced Surface Water Treatment Rule
IFE	individual filter effluents
LCR	Lead and Copper Rule
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
MCLG	maximum contaminant level goal
M/DBP	microbial disinfection byproducts
MF	microfiltration
MGD	millions gallon per day
MIB	2-methylisoborneol
MRDL	maximum residual disinfection level
MRDLG	maximum residual disinfection level goal
MWCO	molecular weight cutoff
N.d.	no date
ND	non-detectable
NF	nanofiltration
NOM	natural organic matter
NPDES	National Pollutant Discharge Elimination System
NTNCWS	non-transient non-community water system
NTU	nephelometric turbidity unit
OCl	hypochlorite ion
OCCT	optimal corrosion control treatment
O&M	operations and maintenance
ORP	oxidation reduction potential
PAC	powder activated carbon
PACl	polyaluminum chloride
POTW	publicly owned treatment works
PWS	public water system
RAA	running annual average
RCAP	Rural Community Assistance Partnership
RCRA	Resource Conservation and Recovery Act
RMP	Risk Management Plan
RO	reverse osmosis
SDS	simulated distribution system
SCADA	Supervisory Control and Data Acquisition
SOC	synthetic organic chemicals
SDWA	Safe Drinking Water Act
Stage 1 D/DBPR	Stage 1 Disinfectants and Disinfection Byproducts Rule
Stage 2 D/DBPR	Stage 2 Disinfectants and Disinfection Byproducts Rule

SUVA	specific ultraviolet absorbance
SWTR	Surface Water Treatment Rule
T	contact time in minutes (in CT calculations)
TCR	Total Coliform Rule
TDS	total dissolved solids
TENORM	technologically enhanced naturally occurring radioactive materials
THM	trihalomethane
TTHM	total trihalomethane (sum of chloroform, BDCM, DBCM, and bromoform)
TTHMFP	total trihalomethane formation potential
TOC	total organic carbon
TOP	Texas Optimization Program
TSO	total system optimization
UF	ultrafiltration
UFC	uniform formation conditions
UPS	universal power supply
UV	ultraviolet light
UVT	ultraviolet light transmittance
VOC	volatile organic compound
WEF	Water Environment Foundation
WFP	water filtration plant
WTP	water treatment plant
WWTP	wastewater treatment plant

1 Introduction

The Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) and the Stage 2 Disinfectants and Disinfection Byproducts Rule (DBPR) were developed and promulgated together to address risk trade-offs between two different types of contaminants: microbial pathogens and disinfection byproducts. The U.S. Environmental Protection Agency (EPA) recognizes that systems may encounter compliance issues with the Stage 2 DBPR when making changes to comply with the LT2ESWTR, and vice versa. In addition to the challenges of complying with the suite of microbial/disinfection byproduct (M/DBP) rules simultaneously, a water system must also ensure that changes in treatment to comply with those rules do not adversely affect compliance with other drinking water regulations.

This chapter answers the questions:

1.1 What is the purpose of this guidance manual?
1.2 What is "Simultaneous Compliance"?
1.3 Does this manual address compliance with environmental regulations other than Safe Drinking Water Act regulations?
1.4 Who should use this guidance manual? How should it be used?
1.5 How is this manual organized?
1.6 Can I rely on this guidance manual alone to make compliance decisions?
1.7 Are there quick references I can use to screen for potential simultaneous compliance problems?
1.8 Where can I get help achieving simultaneous compliance?
1.9 What additional resources are available?

1.1 What is the purpose of this guidance manual?

The purpose of this guidance manual is to help water systems and their regulators ***identify and mitigate*** potential simultaneous compliance issues that may arise when systems make changes to comply with the LT2ESWTR and/or the Stage 2 DBPR. The manual lists possible ways that simultaneous compliance issues could be addressed. In addition, tools are recommended and described to help determine if potential issues may affect a given system.

This manual addresses simultaneous compliance issues that may arise as systems make treatment changes to comply with the LT2ESWTR and/or the Stage 2 DBPR.

Another key purpose of this manual is to provide a ***clearinghouse of information***, directing the reader to helpful resources. It would not be practical for one document to contain comprehensive technical and operational information for all of the Stage 2 DBPR and LT2ESWTR compliance treatment technologies. Each public water system (PWS) has different source water, existing treatment processes, distribution system materials, layout, storage, operations, and other characteristics that should be evaluated and addressed by the system in conjunction with the state and if necessary outside technical consultants, to ensure long-term compliance. EPA has designed this manual to raise potential simultaneous compliance issues, and directs readers to other references for more in-depth information.

After the draft version of this manual was released for public comment in September of 2006, the Ground Water Rule (GWR) was promulgated in November of 2006. Most simultaneous compliance issues faced by systems using disinfection to comply with the GWR are already covered in the main body of this manual. EPA has identified a few issues, however, that may be unique, such as when ground water systems add disinfection for the first time. These issues and recommendations for addressing them are included in a new appendix (Appendix F).

1.2 What is "Simultaneous Compliance"?

For the purposes of this guidance manual, simultaneous compliance means compliance with ***all existing Safe Drinking Water Act (SDWA) regulations***, as summarized in Exhibit 1.1. Two-page fact sheets for many of the regulations are included in Appendix A. While systems may be concerned with issues pertaining to emerging contaminants, this guidance manual is not designed to address these concerns and does not discuss these issues.

1.3 Does this manual address compliance with environmental regulations other than SDWA regulations?

In addition to SDWA regulatory issues, systems should always weigh operational issues and compliance with other environmental regulations when considering a treatment change. While this document provides some discussion of non-SDWA regulations and other compliance challenges (e.g. discharge permits, sludge disposal), readers should seek additional guidance and other technical references for addressing these compliance issues.

1.4 Who should use this guidance manual? How should it be used?

This manual is for systems that already know they need to make a change in operations or treatment.

This manual should be used by public water systems that already know they need to make a change to comply with the requirements of the LT2ESTWR and/or the Stage 2 DBPR. The manual is targeted to water system managers, engineers, consultants, and regulators. It assumes that readers have a technical background and some familiarity with water treatment processes (for readers without this background, see Section 1.8 for how to obtain technical assistance).

This manual should be used as a technical resource as systems select a treatment alternative or operational change. Example 1.1 shows how managers of a hypothetical system could use this manual to help inform their decision-making about treatment changes to comply with the LT2ESWTR. Example 1.2 shows how a regulator working with the same hypothetical system could also use this guidance manual as a technical resource.

Before considering a treatment or operational change to achieve compliance with the LT2ESWTR and/or Stage 2 DBPR, water systems should make sure their sources are well-managed for both for quantity and quality and existing treatment processes are working well. For surface water systems, treatment plant performance should be optimized for disinfectant byproduct (DBP) precursor removal, filtered water turbidity should be well-controlled, and disinfectants should be applied for sufficient time and at sufficient concentrations for inactivation of microbial pathogens. All water systems should actively manage their distribution systems to meet water demand and provide consistently good water quality. EPA encourages systems to take advantage of existing voluntary programs in place including the Partnership for Safe Water, Qualserve, and Areawide Optimization. Appendix E describes these and other programs that can be used to achieve simultaneous compliance.

Exhibit 1.1 Existing SDWA Regulations as of March, 2007

Rule/Memo	***Date of Promulgation***	***Contaminant of Concern***	***Rule Summary Information Available from EPA***
Ground Water Rule (GWR)	November 2006	Source Water Microbial Pathogens	Fact Sheet, included in Appendix A
Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR)	January 2006	Source Water Microbial Pathogens	Fact Sheet, included in Appendix A
Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2 DBPR)	January 2006	Disinfection Byproducts	Fact Sheet, included in Appendix A
Arsenic and Clarifications to Compliance and New Source Monitoring Rule	January 2001	Arsenic	Quick Reference Guide, included in Appendix A
Lead and Copper Rule (LCR)	June 1991	Lead and Copper	Quick Reference Guide, Included in Appendix A
LCR Clarification of Requirements for Collecting Samples and Calculating Compliance	November 2004	Lead and Copper	Fact Sheet, included in Appendix A
Total Coliform Rule (TCR)	June 1989	Distribution System Microbial Pathogens	Quick Reference Guide, included in Appendix A
Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 D/DBPR)	December 1998	Disinfectants and Disinfection Byproducts	Quick Reference Guide, included in Appendix A
Interim Enhanced Surface Water Treatment Rule (IESWTR)	December 1998	Source Water Microbial Pathogens	Quick Reference Guide, included in Appendix A
Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR)	January 2002	Source Water Microbial Pathogens	Quick Reference Guide, included in Appendix A
Filter Backwash Recycling Rule (FBRR)	June 2001	Filter Backwash (Microbial Pathogens)	Quick Reference Guide, included in Appendix A
Surface Water Treatment Rule (SWTR)	June 1989	Source Water Microbial Pathogens	Summary information on the web at http://www.epa.gov/safewater/therule.html#Surface

Example 1.1 How this Manual can Help Water System Personnel Better Understand Their Choices

System A is a community water system serving filtered surface water to 11,000 people. Based on source water *Cryptosporidium* data the system has begun to collect, System A will likely be placed in the second LT2ESWTR bin and therefore will need an additional 1.0 log *Cryptosporidium* removal or inactivation. The system hired an engineer to conduct a feasibility study. The engineer recommended three possible compliance options:

- Bank filtration
- Bag filters
- Ozone

Before discussing any of them with their state regulator or recommending any of them to their water board, System A wanted more information on each technique. In addition to worrying about costs and operational challenges, the staff is concerned that making a change to comply with LT2ESWTR might put them out of compliance with another drinking water regulation.

System A picks up this *Simultaneous Compliance Guidance Manual* and

- Refers to Chapter 2 for summaries of the issues that pertain to these three treatment alternatives.
- Reads Section 4.4 *Other Microbial Removal Technologies* in Chapter 4 for information on simultaneous compliance issues associated with bank filtration and bag filters.
- Reads Section 5.2 *Ozonation* in Chapter 5 for information on simultaneous compliance issues associated with ozone.
- Gets additional references about bank filtration, bag filters, and ozone from Chapter 7.
- Reviews Section 5.5 *Primary and Residual Disinfectant Use* in Chapter 5 to see what issues might arise using the combination of ozone as primary disinfectant and free chlorine as residual disinfectant.
- Based on their reading, System A want to know more about whether they might have distribution system biofilm problems from switching to ozone. They refer to Appendix C *Guidelines for Evaluating Potential Impacts of Treatment Changes on Distribution Systems* and read the section on adding ozone and the section on installing ozone without subsequent biological filtration.
- System A decides it would be beneficial to know how each of the treatment alternatives could be evaluated more before installation. They read through Section 6.3 *Tools for Gathering Information* and identify tools that may be helpful for evaluating the three alternatives.

While they still have many questions for their engineer and have not yet chosen a treatment technique, System A's managers feel more prepared to discuss the pros and cons of each alternative. They have identified questions they would like answered before they take the next step.

Example 1.2 How This Manual Can Help Regulators Understand Potential Simultaneous Compliance Issues

The state is scheduled to meet with System A to discuss the possibility of installing ozone treatment to comply with the LT2ESWTR. The state's engineers are concerned that this change could potentially make it difficult for System A to comply with other regulations. They're particularly concerned with bacteriological regrowth in the distribution system.

They pick up this *Simultaneous Compliance Guidance Manual* and

- Read Section 5.2 *Ozonation* in Chapter 5 for information on simultaneous compliance issues associated with ozone.
- Refer to Appendix C *Guidelines for Evaluating Potential Impacts of Treatment Changes on Distribution Systems* and read the section on adding ozone and the section on installing ozone without subsequent biological filtration.
- Read Case Study #10: Ozonation for an example of how one water system used ozone to control microbial regrowth potential in the distribution system.

The regulators have many questions for System A, but are more prepared to discuss the prospect of ozone as a way for the system to comply with their *Cryptosporidium* treatment requirement.

1.5 How is this manual organized?

Exhibits 1.2 and 1.3 summarize the contents of each chapter and appendix in this guidance manual.

Chapter 2 provides tables that summarize the potential benefits and conflicts of LT2ESWTR and Stage 2 DBPR compliance technologies, operational issues that should be considered, and tools that systems can use to evaluate a treatment technology's potential for causing simultaneous compliance problems.

Chapters 3 through 5 of the manual are organized by ***treatment technology***. This enables the reader to refer to a particular section for a comprehensive discussion of simultaneous compliance issues related to that treatment technique. For example, if the reader is considering installing chloramines to achieve compliance with the Stage 2 DBPR, the reader should refer to Section 5.1 for a discussion of pertinent simultaneous compliance issues that relate to using chloramines. Exhibit 1.4 provides brief descriptions of the treatment technologies and operational changes identified as compliance options in this guidance manual.

Within Chapters 3 through 5, each section on a treatment technique is organized as follows:

- A summary of **Advantages** of the treatment technique;
- **Potential Operational and Simultaneous Compliance Issues**, including recommendations for addressing each issue; and
- **Recommendations for Gathering More Information**, including suggestions for additional monitoring, tools that are available for collecting additional system information, and a short description of related case studies.

Chapter 6 identifies issues that should be considered before a change in treatment or operations is made. It also describes tools available to help systems collect information that is applicable and helpful for making their compliance decisions.

Chapter 7 provides a complete reference list, grouped by subject and also listed alphabetically. Most of the subject headings in Chapter 7 correspond to specific treatment technologies. Exceptions include technical references for DBP formation, technical references for corrosion, and general water treatment references.

Exhibit 1.2 Organization of the Chapters

Ch #...	***Is titled...***	***and has information on...***
2	Quick Reference Materials for Simultaneous Compliance	• A checklist to help systems quickly identify simultaneous compliance issues • Tables summarizing compliance, operational, and water quality issues for each compliance technology • Tables summarizing tools and pertinent case studies
3	Improving and Optimizing Current Operations	• Source Management • Distribution System Best Management Practices • Moving Point of Chlorination • Decreasing pH • Reducing Chlorine Dose Under Warm Water Conditions • Modifying Presedimentation Basin Operations • Enhanced Coagulation • Enhanced Softening
4	Installing New Total Organic Carbon or Microbial Removal Technologies	• Granular Activated Carbon • Microfiltration/Ultrafiltration (MF/UF) • Nanofiltration • Other Microbial Removal Technologies
5	Alternative Disinfection Strategies	• Chloramines • Ozone • Ultraviolet Light • Chlorine Dioxide • Primary and Secondary (residual) Disinfectant Use
6	Making M/DBP Compliance Decisions	Tools available for: • Water Quality Monitoring • Hydraulic and Water Quality Modeling for Distribution Systems • Desktop Evaluations • Bench-Scale Testing • Pilot Testing • Full-Scale Applications • Cost Estimation • Community Preferences
7	References	Technical references grouped by subject and also listed alphabetically

Exhibit 1.3 Organization of the Appendices

Appendix…	*is titled...*	*and has information on...*
A	Summary of Pertinent Drinking Water Regulations	Summaries of major EPA drinking water regulations in the form of 2-page fact sheets and quick reference guides.
B	Case Studies	Case studies illustrating simultaneous compliance challenges that water systems have encountered when implementing treatment techniques to help comply with one or more of the M/DBP rules.
C	Guidelines for Evaluating Potential Impacts of Treatment Changes on Distribution Systems	Summary of issues that may arise in the distribution system as a result of changes made during treatment.
D	Tools for Evaluating Impacts of Treatment Changes on Lead and Copper Rule Compliance	Tools that can be used to test impacts of a water quality change on corrosion, which can result in violations of the LCR. References for further information are also included.
E	Innovative Management Tools for Achieving Simultaneous Compliance	Existing and developing programs that can help water systems comply with regulations and produce consistently high quality water. Contains descriptions of performance-driven optimization programs and integrated management approaches that consider treatment processes and operating practices throughout the entire water system.
F	Considerations for Systems Complying with the Ground Water Rule	Considers unique challenges that may emerge when systems make treatment or source changes to comply with the GWR. Contains a brief overview of the GWR and a discussion of corrective actions that could create simultaneous compliance issues.

Exhibit 1.4 Treatment Technologies and Operational Changes Addressed in this Guidance Manual[1]

Technology or Operational Change	Description
Source Management (sec. 3.1)	Management techniques that manipulate a source(s) to provide water with the lowest concentration of DBP precursors or pathogens possible.
Distribution System Best Management Practices (sec.3.2)	Management techniques designed to maintain the integrity of the distribution system and limit or reduce microbial growth, DBPs, or incursion into the distribution system.
Moving Point of Chlorination (sec.3.3)	Moving chlorination further downstream in the plant to a point where more DBP precursor removal has taken place.
Modifying pH during Chlorination (sec.3.4)	Lowering the pH of the water during the chlorination process.
Reducing Chlorine Dose under Warm Water Conditions (sec.3.5)	Lowering the chlorine dose under warmer water temperature conditions.
Modifying Presedimentation Basin Operations (sec.3.6)	Changing operation of presedimentation basins to achieve more removal of pathogens by adding coagulant or increasing residence time.
Enhanced Coagulation (sec.3.7)	Achieving more organic carbon removal by using higher coagulant doses under lower pH conditions.
Enhanced Softening (sec.3.8)	Achieving more organic carbon removal by adding coagulant and increasing the lime dose to raise the pH.
Granular Activated Carbon (sec.4.1)	Filtering water through a bed of granular activated carbon either by itself or as part of a granular filter.
Microfiltration/Ultrafiltration (MF/UF) (sec.4.2)	A low pressure membrane process used to remove microbes and some organic carbon.
Nanofiltration (sec.4.3)	A pressure membrane process used to remove particles and some dissolved organic matter. Nanofiltration uses membranes with smaller pores than MF/UF.
Improved Filtration Performance (sec.4.4)	Changes in the operation of filters to lower the effluent turbidity to below 0.10 NTU.
Slow Sand Filtration (sec.4.4)	A gravity filtration process using sand as the filtration medium.
Diatomaceous Earth Filtration (sec.4.4)	Filtration through a layer of diatomaceous earth placed on a permeable membrane. It can be a pressure or vacuum process.
River Bank Filtration (sec.4.4)	A filtration process that uses vertical or horizontal wells drilled near a river bank to filter the water through the river bank material.
Bag Filtration (sec.4.4)	A filtration process that filters water through a fabric material.
Cartridge Filtration (sec.4.4)	A pressure filtration process that filters water through a membrane cartridge.
Chloramines (sec.5.1)	Adding chloramines to the water to achieve disinfection. Chloramines are formed by adding chlorine and ammonia together in water.
Ozone (sec.5.2)	Adding ozone to water to achieve disinfection. Ozone is generated on site using oxygen.
Ultraviolet Light (sec.5.3)	Passing light from ultraviolet lamps through the water to achieve disinfection.
Chlorine Dioxide (sec.5.4)	Adding chlorine dioxide to water to achieve disinfection. Chlorine dioxide is generated on site.

[1] These technologies and operational changes are not necessarily appropriate for every system; rather they are approaches that systems may opt to pursue based on a system-specific analysis.

1.6 Can I rely on this guidance manual alone to make compliance decisions?

No, this guidance manual alone is not intended to provide comprehensive technical guidance for systems making treatment modifications. Instead, systems are encouraged to use this manual as a technical resource to identify potential issues and possible solutions to those issues. Chapter 6 describes the potential tools for assessing compliance choices. Chapter 7 provides an extensive reference list, grouped by subject matter, which systems can use to obtain more information as they plan treatment modifications. Systems should take into account source water characteristics, existing treatment processes, distribution system issues, available resources, and other system-specific information in determining the best compliance approach.

This guidance manual is just one of many guidance manuals EPA has developed or is developing to help systems comply with the rules under the Safe Drinking Water Act. EPA recommends systems first visit EPA's websites for the Stage 2 DBPR (http://www.epa.gov/OGWDW/disinfection/stage2) and the LT2ESWTR (http://www.epa.gov/OGWDW/disinfection/lt2). These websites have a wealth of technical links to assist systems with identifying their compliance requirements and options. Readers can also visit http://www.epa.gov/safewater for general regulatory information.

In addition, each state may have its own rules and regulations pertaining to treatment modifications. For example, many states have review and approval procedures that must be followed before making any compliance decisions. Systems should contact their state for further information.

1.7 Are there quick references I can use to screen for potential simultaneous compliance problems?

Yes, Exhibit 2.1 in Chapter 2 is a one-page checklist that systems can use to quickly identify key potential operational and simultaneous compliance issues. This checklist could be particularly helpful for small systems or systems with limited resources. Chapter 2 also provides the following summary tables to help systems screen for potential issues:

- Exhibit 2.2 Technology Alternatives and How They Potentially Affect Water Quality
- Exhibit 2.3 Stage 2 DBPR and LT2ESWTR Compliance Technologies: Summary of Benefits and Potential Conflicts
- Exhibit 2.4 Potential Operational Issues for Different Treatment Modifications
- Exhibit 2.5 Case Studies in this Guidance Manual and Issues They Address
- Exhibit 2.6 Tools for Gathering System-Specific Information on Different Compliance Techniques

1.8 Where can I get help achieving simultaneous compliance?

Some water system engineers and managers may need assistance understanding the more technically complex portions of this guidance manual. Others may need assistance weighing which of the potential issues are likely to occur in their system. EPA encourages these readers to seek help from their regulators, technical assistance providers, or consulting engineers. In addition, small water system managers are encouraged to seek help from their state, local Rural Water Association circuit riders, or the Rural Community Assistance Partnership (RCAP). EPA has also published small entity compliance guides for both the LT2ESWTR (USEPA 2007a) and the Stage 2 DBPR (USEPA 2007b).

Troubleshooting Guides

Some water systems may encounter problems with their treatment performance or finished water quality as they modify treatment to comply with the new regulations. Here are a few troubleshooting guides that can help those systems (and systems in general) identify and address treatment problems:

Bevery, R.P. 2005. *Filter Troubleshooting and Design Handbook*. 425 pp. Denver: AWWA.

Lauer, W.C. 2004. *Water Quality Complaint Investigator's Field Guide*. 102pp. Denver: AWWA.

Logsdon, G.S., A.F. Hess, M.J. Chipps, and A.J. Rachwal. 2002. *Filter Maintenance and Operations Guidance Manual*. AwwaRF Report 90908. Project #2511. Denver: AwwaRF.

Tillman, G.M. 1996. *Water Treatment: Troubleshooting and Problem Solving*. 176 pp. Boca Raton: CRC Press LLC.

1.9 What additional resources are available?

Chapter 7 contains a comprehensive list of references, grouped by subject. EPA references are discussed below. In addition to these many references, the American Water Works Association Research Foundation (AwwaRF) is currently developing a decision tool to help utilities develop simultaneous compliance strategies (Project #3115). Publication of this tool is expected in 2008.

The 1999 M-DBP Simultaneous Compliance Guidance Manual

The *Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual* (USEPA 1999f) was published in conjunction with the promulgation of the Stage 1 D/DBPR and the Interim Enhanced Surface Water Treatment Rule (IESWTR). The 1999 manual is organized by regulation, describing how compliance with the Stage 1 D/DBPR or IESWTR might affect compliance with another regulation, focusing on one regulation at a time. Some readers may be more comfortable with that layout.

Since several issues discussed in the 1999 manual continue to be issues that present challenges to systems trying to comply with the LT2ESWTR and Stage 2 DBPR, readers could also refer to the 1999 manual for guidance. The 2007 Simultaneous Compliance Guidance Manual, however, provides more up-to-date findings and references. It also focuses more specifically on those technologies that have been identified as treatment solutions for complying with the requirements of the LT2ESWTR and the Stage 2 DBPR.

Additional EPA References

In conjunction with promulgation of the IESWTR, Stage 1 D/DBPR, Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR), LT2ESWTR, and the Stage 2 DBPR, EPA has published several guidance manuals that may assist PWSs in resolving potential conflicts. Complete references for these guidance manuals are provided in Chapter 7. These references include the following:

- *Handbook: Optimizing Water Treatment Plant Performance Using the Composite Correction Program* (USEPA 1998a)
- *Disinfection Profiling and Benchmarking Guidance Manual* (USEPA 1999a)
- *Alternative Disinfectants and Oxidants Guidance Manual* (USEPA 1999b)
- *Uncovered Finished Water Reservoirs Guidance Manual* (USEPA 1999c)
- *Guidance Manual for Compliance with the Interim Enhanced Surface Water Treatment Rule: Turbidity Provisions* (USEPA 1999d)
- *Unfiltered Water Supply Systems Guidance Manual* (USEPA 1999e)
- *Guidance Manual for Conducting Sanitary Surveys of Public Water Systems; Surface Water and Ground Water Under the Direct Influence (GWUDI)* (USEPA 1999g)
- *Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual* (USEPA 1999h)
- *Implementation Guidance for the Stage 1 Disinfectants/Disinfection Byproducts Rule* (USEPA 2001a)
- *Low Pressure Membrane Filtration for Pathogen Removal: Application, Implementation, and Regulatory Issues* (USEPA 2001h)
- *Controlling Disinfection By-Products and Microbial Contaminants in Drinking Water* (USEPA 2001c)
- *Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule* (USEPA 2006b)
- *Membrane Filtration Guidance Manual* (USEPA 2005b)
- *Long Term 1 Enhanced Surface Water Treatment Rule Turbidity Provisions Technical Guidance Manual* (USEPA 2004h)

- *Complying with the Long Term 2 Enhanced Surface Water Treatment Rule: Small Entity Compliance Guide (*USEPA 2007a*)*

- *Complying with the Stage 2 Disinfectants and Disinfection Byproduct Rule: Small Entity Compliance Guide (*USEPA 2007b*)*

Several additional guidance manuals are under development and will be published to help water systems comply with the requirements of the Stage 2 DBPR, LT2ESWTR and the Ground Water Rule. Information on these manuals is provided in Exhibit 1.5.

Exhibit 1.5 EPA Guidance Manuals under Development

Rule	Guidance Manual	Weblink for Updates
LT2ESWTR	*Microbial Toolbox Guidance Manual*	http://www.epa.gov/safewater/disinfection/lt2/compliance.html
	LT2ESWTR Implementation Guidance	
Stage 2 DBPR	*Consecutive Systems Guidance Manual for the Stage 2 DBPR*	http://www.epa.gov/safewater/disinfection/stage2/compliance.html
	Operational Evaluation Guidance Manual	
	Stage 2 DBPR Implementation Guidance	
GWR	*Consecutive Systems Guidance Manual for the GWR*	http://www.epa.gov/safewater/disinfection/gwr/compliancehelp.html
	Source Water Monitoring Guidance Manual	
	Source Water Assessment Guidance Manual	
	Corrective Actions Guidance Manual	
	Sanitary Survey Guidance Manual	
	Complying with the GWR: Small Entity Compliance Guide	
	GWR Implementation Guidance	

2 Quick Reference Materials for Simultaneous Compliance

This Chapter provides matrices that can be used as screening tools by systems and states to quickly identify potential simultaneous compliance issues, while the later chapters provide a detailed discussion of these issues.

- Exhibit 2.1 (page 2-2) is a **checklist** that can be used to quickly identify potential operational and simultaneous compliance issues. It may be particularly useful for small systems or systems with limited resources.

- Exhibit 2.2 (starting on page 2-3) provides a summary of how different compliance technologies may affect **water quality**. For example, while switching from chlorine to UV will increase inactivation of *Cryptosporidium*, it may decrease inactivation for viruses. Note that the changes shown in this exhibit may or may not occur at a specific water system; they are listed so that systems and states will be aware of them and the possibility that they may be an issue.

- Exhibit 2.3 (starting on page 2-6) **summarizes simultaneous compliance issues** for individual LT2ESWTR and Stage 2 DBPR compliance technologies. For some treatment strategies listed, no significant impact on drinking water regulations is anticipated. Systems may, however, encounter other challenges, such as an increase in waste residuals or a reduction in the quantity of treated water that can be produced.

- Exhibit 2.4 (starting on page 2-12) identifies potential **operational issues** for individual LT2ESWTR and Stage 2 DBPR compliance technologies. Note that the operational issues shown in this exhibit may or may not occur at a specific water system; they are listed so that systems and states will be aware of them and the possibility that they may be an issue.

- Exhibit 2.5 (starting on page 2-13) provides summary information on each of the **case studies** in Appendix B. The case studies give real-world examples of how systems have dealt with simultaneous compliance issues with past regulations and in anticipation of the Stage 2 DBPR and LT2ESWTR.

- Exhibit 2.6 (page 2-16) lists **tools** that can be used to gather more information on how a system may be affected by a treatment change.

If you are considering a treatment modification or a new treatment to meet the LT2ESWTR or Stage 2 DBPR, this checklist can help you see if you might have problems complying with other drinking water regulations. If you answer "yes" to any of these questions, go to the section in Chapter 3, 4, or 5 that addresses your treatment change. There you will find a list of potential simultaneous compliance issues, suggestions for how to address them, and other helpful information. If you are not sure how to answer any of these questions or need help understanding the water quality impacts of a treatment change, consult your state regulator, technical assistance provider, or a consulting engineer.

Exhibit 2.1 Checklist for Identifying Key Operational and Simultaneous Compliance Issues

Yes	**No**	
☐	☐	***Will you be getting less CT (measured as log inactivation) for any regulated microorganism (i.e. viruses, Giardia, or Cryptosporidium) as a result of the treatment change?*** If you answered "yes" and are a surface water system, you must conduct disinfection benchmarking and profiling. If you are a ground water system required to meet 4-log inactivation, you must continue to meet 4-log inactivation.
☐	☐	***Will the treatment change cause an increase (seasonal or permanent) in organic carbon at any point before disinfectant addition?*** If yes, you could potentially have problems complying with the Stage 1 DBPR, the Stage 2 DBPR, or the TCR.
☐	☐	***Will the treatment change the pH and/or alkalinity of your finished water*?** If yes, your finished water could be more corrosive and you could have problems complying with the LCR.
☐	☐	***Will you be using a different residual disinfectant or a different concentration of residual disinfectant?*** Disinfectant residual changes can impact TCR and LCR compliance.
☐	☐	***Will the treatment change affect the quality of water being filtered?*** A change in coagulation or pre-disinfection could affect filter performance and compliance with the LT1ESWTR or IESWTR.
☐	☐	***Will the treatment change result in higher or lower concentrations of inorganics, such as manganese, iron, aluminum, sulfate, chloride, or sodium in your finished water?*** If yes, your water could become more corrosive and you could have problems complying with the LCR. You could also have aesthetic problems.
☐	☐	***Will the treatment change cause an increase in production of waste residuals (e.g., enhanced coagulation could cause your system to produce more sludge)?*** This will not typically cause any rule violations but may require increased land disposal area, and increased residual production can present operational challenges for your system.

Exhibit 2.2 Technology Alternatives and How They Potentially Affect Water Quality

	Inactivation of microbial pathogens	**pH**	**alkalinity**	**disinfectant residual[1]**	**iron or manganese**	**turbidity**	**NOM**	**DBPs**	**corrosivity**	**AOC**	**taste and odor**
Source Management[2]	May decrease if colder water is used	may increase or decrease	may increase or decrease		may increase		may decrease	may decrease	may increase or decrease		may increase
Distribution System BMPs				may increase		may increase if flushing not done properly		TTHM may decrease; HAA5 may decrease or increase	may decrease		may increase
Moving the Point of Chlorination Downstream	May decrease			may increase or decrease	may increase			decrease			
Decreasing pH	Increase (for chlorine only)	decrease	may decrease					TTHM may decrease, HAA5 may increase	may increase		
Reducing Chlorine Dose Under Warmer Water Conditions	may decrease	may increase or decrease		may decrease				decrease			
Presedimentation					may decrease	may decrease	may decrease	may decrease			
Enhanced Coagulation	may increase	decrease	may decrease		manganese may increase	may increase or decrease	decrease	decrease	may increase		
Softening/ Enhanced Softening	may increase, may decrease due to high pH	increase	may increase		may decrease	may decrease	may decrease	HAA5 may decrease, TTHM may increase	concrete corrosion may increase		

	Inactivation of microbial pathogens	pH	alkalinity	disinfectant residual[1]	iron or manganese	turbidity	NOM	DBPs	corrosivity	AOC	taste and odor
GAC						may increase due to GAC fines	decrease	decrease		may decrease if GAC is biologically active	decrease
Microfiltration/ Ultrafiltration					may decrease	decrease		may decrease			
Nanofiltration		may decrease	may decrease		decrease	decrease	may decrease	decrease	increase	may decrease	
Bank Filtration					may increase						
Bag Filtration					may decrease	may decrease					
Cartridge Filtration					may decrease	may decrease					
Second Stage Filtration					may decrease	decrease	may decrease	may decrease		may decrease	
Slow Sand Filtration					may decrease	may decrease	may decrease	may decrease			
DE Filtration					may decrease	may decrease					
Improved Filter Performance					may decrease	decrease	may decrease	may decrease			
Chloramines[3]	decrease			may increase				TTHM and HAA5 will decrease	may increase or decrease		may increase or decrease
Ozone[3]	increase for protozoa							may decrease, but increase in bromate	may increase or decrease		may increase or decrease
UV Disinfection[3]	UV dose is low for protozoa, need higher dose for viruses							decrease			

	Inactivation of microbial pathogens	**pH**	**alkalinity**	**disinfectant residual[1]**	**iron or manganese**	**turbidity**	**NOM**	**DBPs**	**corrosivity**	**AOC**	**taste and odor**
Chlorine Dioxide[3]	increase for protozoa, decrease for viruses				may decrease if followed by filtration			TTHM and HAA5 decrease, chlorite will be formed			may increase or decrease

[1] Refers to the disinfectant residual in distribution system water.

[2] For the purpose of this guidance, *source management* refers to techniques water systems can use to manipulate their water sources to comply with Stage 2 DBPR or LT2ESWTR regulations. In this context, source management does not refer to source water protection or other long-term watershed efforts to improve water quality. The source management techniques discussed in this section are operational changes made by water systems to use the source with the least amount of natural organic matter (NOM), or selecting a blend of sources to try to achieve the most effective treatment for organics and turbidity removal. Source management strategies can affect raw water quality or they can affect finished water quality directly (e.g., blending or alternating sources).

[3] Water quality changes for alternative disinfectants are compared to conditions when free chlorine is used.

Exhibit 2.3 Stage 2 DBPR and LT2ESWTR Compliance Technologies: Summary of Benefits and Potential Conflicts

System Modification / Compliance Technology	Used for Compliance with		Potential Benefits	Potential Issues		
	Stage 2 DBPR	LT2ESWTR		Description	SDWA Rule(s) of Concern	Where It's Discussed in More Detail
Source Management	X	X	• may reduce DBP precursors • may reduce disinfectant demand • can improve treatability of raw water for turbidity and/or DBP precursor removal • may reduce pathogen and particle loading	• water temperature change may affect CT and coagulation/flocculation • may introduce new contaminants (e.g. iron, manganese, sulfide) • raw water pH change can adversely affect water treatment and/or corrosion control • may increase coagulant demand • may increase disinfectant demand • change in aesthetic quality may generate customer complaints	SWTR, Stage 1 DBPR, Stage 2 DBPR, IESWTR, LT1ESWTR, LCR.	Section 3.1
Distribution System BMPs	X		• targets specific problem areas • can improve microbial control • can reduce corrosion • can reduce nitrification • improves chlorine residual maintenance	• can stir up sediments • issues with disposal of chlorinated water • lining materials may leach into water • less storage available for emergencies • increased water loss	TCR, Stage 1 DBPR, Stage 2 DBPR.	Section 3.2
Moving the Point of Chlorination Downstream	X		• reduces DBP concentrations • reduces amount of disinfectant used • can facilitate monthly total organic carbon (TOC) source water monitoring	• May impact ability to meet CT requirements • increases chances of filter fouling • may reduce Asiatic clam or zebra mussel control • provides less effective treatment for iron or manganese • may limit coagulation and filtration effectiveness • may need to increase disinfectant dosage, which could produce more DBPs	IESWTR, LT1ESWTR, LT2ESWTR, Stage 1 DBPR.	Section 3.3

System Modification / Compliance Technology	Used for Compliance with		Potential Benefits	Potential Issues		
	Stage 2 DBPR	LT2ESWTR		Description	Rule(s) of Concern	Where It's Discussed in More Detail
Decreasing pH	X		• same inactivation can be achieved with lower disinfectant dose or shorter free chlorine contact time • lower pH may reduce some DBPs	• may increase HAA5 • can adversely affect treatment plant equipment • may impact settling and sludge dewatering • can cause corrosion problems • may be difficult to maintain a residual	Stage 1 IESWTR, LT1ESWTR, LCR.	Section 3.4
Reducing Chlorine Dose under Warm Water Conditions	X		• Comparable pathogen inactivation with less chlorine • Reduction in TTHM and HAA5 Formation	• Higher disinfectant residual needed for addressing seasonal pathogens • Distribution system impacts if finished water chlorine concentration is decreased	IESWTR, LT1ESWTR, TCR, SWTR.	Section 3.5
Presedimentation		X	• removes *Cryptosporidium* • can remove DBP precursors • reduced solids loading and enhanced stability of water	• algal growth in basins can increase DBP precursors • removal of solids difficult	Stage 1 DBPR, Stage 2 DBPR.	Section 3.6
Enhanced Coagulation	X		• may improve disinfection effectiveness • can reduce bromate formation by reducing pH • can reduce DBP formation • can enhance arsenic and radionuclide removal	• may adversely impact finished water turbidity • lower pH can cause corrosion problems • may see increased inorganics concentrations in finished water • issues with disposal of residuals	IESWTR, LT1ESWTR, LCR, FBRR.	Section 3.7

System Modification / Compliance Technology	Used for Compliance with		Potential Benefits	Potential Issues		
	Stage 2 DBPR	LT2ESWTR		Description	Rule(s) of Concern	Where It's Discussed in More Detail
Softening/ Enhanced Softening	X	X	• removes DBP precursors • two stage plants can achieve *Cryptosporidium* removal credit • lower corrosion impacts	• options for disinfection are limited • may increase scaling in treatment plant and distribution system piping • higher TTHM formation at high pH (may be offset by lower precursors) • pH adjustment may be needed for distribution system and for disinfection effectiveness • increased sludge volume and change in sludge characteristics	SWTR, IESWTR, LT1ESWTR, LT2ESWTR, Stage 1 DBPR.	Section 3.8
Granular Activated Carbon (GAC)	X	X	• removes DBP precursors • can remove taste and odor compounds • if used as secondary filter, can be used to receive C*ryptosporidium* removal credit • removes AOC after ozone when used as biological filter	• may release previously adsorbed compounds • bacteria can be released • fines can foul downstream processes at startup • can limit the ability to pre-chlorinate • chlorate can be formed when GAC comes into contact with chlorine dioxide • ammonia added before GAC may increase nitrification	TCR, IESWTR, LT1ESWTR.	Section 4.1
Microfiltration/ Ultrafiltration		X	• removes bacteria and protozoa • can lower DBPs by allowing lower disinfectant doses • can remove arsenic	• may have increased loss of process water • can be fouled by organics and minerals • additional training required	SWTR.	Section 4.2
Nanofiltration	X	X	• removes microbial pathogens including viruses • can remove DBP precursors • removes arsenic	• can increase corrosiveness of water • issues with reject stream • can be fouled by organics and minerals • additional training required	SWTR, LCR.	Section 4.3
Watershed Control Program	X	X	• removes microbial pathogens • reduces DBP precursor loading • reduces chemical contamination	• none known	None known	Not discussed

System Modification / Compliance Technology	Used for Compliance with		Potential Benefits	Potential Issues		
	Stage 2 DBPR	LT2ESWTR		Description	Rule(s) of Concern	Where It's Discussed in More Detail
Bank Filtration		X	• removes microbial pathogens • decreases turbidity • decreases DBP precursors • relative ease of use	• hydraulic issues • iron/manganese problems • clogging	None known	Section 4.4
Bag Filtration		X	• removes microbial pathogens • relative ease of use	• hydraulic issues • filter fouling	None known	Section 4.4
Cartridge Filtration		X	• removes microbial pathogens • relative ease of use	• hydraulic issues • disposal issues • filter fouling	None known	Section 4.4
Second Stage Filtration	X	X	• reduces particulate matter • reduces DBP precursors • removes microbial pathogens • reduces assimilable organic carbon (AOC)	• hydraulic issues • increased residuals	None known	Section 4.4
Slow Sand Filtration		X	• removes microbial pathogens • may reduce DBP precursors	• hydraulic issues	None known	Section 4.4
Diatomaceous Earth (DE) Filtration		X	• removes microbial pathogens	• hydraulic issues	None known	Section 4.4
Improved Filter Performance		X	• removes microbial pathogens • reduces chemical contaminants • improves aesthetic quality	• increased residuals • disposal issues	None known	Section 4.4

System Modification / Compliance Technology	Used for Compliance with		Potential Benefits	Potential Issues		
	Stage 2 DBPR	LT2ESWTR		Description	Rule(s) of Concern	Where It's Discussed in More Detail
Chloramines	X		• reduce DBPs • may improve biofilm control • may increase ability to maintain disinfectant residual throughout distribution system • may reduce occurrence of *Legionella* in hot water systems	• nitrification may occur in distribution system • may cause corrosion problems with some materials • potential taste and odor problems if improper ratio is used • weaker disinfectant • can be difficult to blend with chlorinated sources • ozone and GAC can lead to faster residual decay • must remove for dialysis patients, fish owners and industrial users.	TCR, IESWTR, SWTR, LCR.	Section 5.1
Ozone	X	X	• inactivates *Cryptosporidium* and *Giardia* • does not form TTHM or HAA5 • effective pre-oxidant • increases UV transmittance of water • disinfection not pH dependent • can oxidize taste and odor compounds • may aid coagulation if fed before coagulant addition point	• may form bromate • forms smaller organic compounds • does not provide a residual in the distribution system • may increase dissolved oxygen in the water • can form taste and odor compounds • can cause corrosion to materials exposed to gas • ozone bubbles can hinder filter performance if not operated properly • switching to ozone and biofiltration can cause the release of manganese from filters • requires additional training	Stage 1 DBPR, TCR, SWTR, LCR, IESWTR, LT1ESWTR.	Section 5.2
Ultraviolet (UV) Disinfection	X	X	• inactivates *Cryptosporidium* and *Giardia* • does not produce regulated DBPs • effectiveness not pH or temperature dependent	• much higher doses needed to inactivate viruses • does not provide a residual • substances in water can interfere with UV disinfection • potential for lamp breakage • power quality problems can cause loss of disinfection • requires additional training	SWTR, IESWTR, LT1ESWTR.	Section 5.3

System Modification / Compliance Technology	Used for Compliance with		Potential Benefits	Potential Issues		
	Stage 2 DBPR	LT2ESWTR		Description	Rule(s) of Concern	Where It's Discussed in More Detail
Chlorine Dioxide	X	X	• achieves some *Cryptosporidium* inactivation • less TTHM and HAA5 formation than with chlorine • oxidizes iron and manganese • disinfection not pH dependent • chlorite residual may inhibit growth of nitrifying bacteria in the distribution system (benefit when using in combination with chloramines)	• forms chlorite which may be a concern for MCL compliance • reduced effectiveness at low temperatures • chlorine dioxide Maximum Residual Disinfectant Level (MRDL) limits application dose • can form brominated DBPs • degrades under UV light • residual dissipates quickly • potential odor problems • requires additional training and safety concerns	Stage 1 DBPR, SWTR, IESWTR, LT1ESWTR.	Section 5.4

Brief descriptions of the treatment alternatives discussed here and later in this guidance manual are provided in Exhibit 1.4.

Exhibit 2.4 Potential Operational Issues for Different Treatment Modifications

Topic is marked with an "X" if it may be a concern for the treatment modification

Treatment Modification	Production Capability	Compatibility with Treatment Facilities	Residual/Disposal Issues	Site Specific Issues	Distribution System Materials	Distribution System Operations	Environmental Issues	Consumer Driven Issues	Preference of Operation Staff	Consecutive System Requirements	Costs [1]	Where it's discussed in more detail
Source Management	X	X	X	X	X	X	X	X		X		Section 3.1
Distribution System BMPs				X	X	X	X	X	X	X		Section 3.2
Moving Point of Chlorination Downstream		X		X	X			X	X	X		Section 3.3
Decreasing pH		X	X	X	X	X			X	X		Section 3.4
Decreasing Chlorine Dose Under Warm Water Conditions				X	X	X		X		X		Section 3.5
Presedimentation		X	X	X					X	X		Section 3.6
Enhanced Coagulation		X	X	X	X	X	X		X	X		Section 3.7
Softening/Enhanced Softening		X	X	X	X	X			X	X		Section 3.8
Granular Activated Carbon		X	X	X	X	X			X	X	X	Section 4.1
Microfiltration/Ultrafiltration	X	X	X	X			X		X	X	X	Section 4.2
Nanofiltration	X	X	X	X	X	X	X		X	X	X	Section 4.3
Bank Filtration	X			X				X				Section 4.4
Other Microbial Removal Technologies (improved filter performance, bag filtration, cartridge filtration, second stage filtration, slow sand filtration, DE filtration)	X	X	X	X					X		X	Section 4.4
Chloramines				X	X	X	X	X	X	X		Section 5.1
Ozone		X		X	X	X		X	X	X	X	Section 5.2
UV Disinfection	X	X		X					X	X	X	Section 5.3
Chlorine Dioxide				X	X	X			X	X	X	Section 5.4

[1] It is important to note that costs are associated with any modification or new treatment. This column is meant to identify changes that are generally more costly compared to others. Also note that some distribution system BMPs, such as looping dead end pipes, can have relatively high costs.

Exhibit 2.5 Case Studies in this Guidance Manual and Issues they Address

Case Study No.	Treatment/Issue Addressed	Utility Name	Case Study Location	Population Served	Average Annual Treatment Plant (MGD) Production	Source Water	Page	Section Where It is Referenced in the Manual
1	Improving and Optimizing Current Operations	Owenton Water Works and Kentucky American TriVillage	Owenton, Kentucky	<10,000	1	Surface Water (reservoir)	B-5	3.3
2	Decreasing pH	Public Utility District #1	Skagit County, Washington	70,000	12	Surface Water (reservoir)	B-11	3.4
3	Presedimentation	Kansas City Water Services	Kansas City, Missouri	>600,000	240	Surface Water (river, ground water under the direct influence of surface water)	B-19	3.6
4	Switching Coagulants	Hillsborough River Water Treatment Plant	Tampa, Florida	>450,000	100	Surface Water (river)	B-23	3.7
5	Enhanced Coagulation - Problems with Copper Pitting	Washington Suburban Sanitary Commission	Montgomery and Prince Georges County, Maryland	1,600,000	167	Surface Water (rivers)	B-29	3.7
6	Enhanced Coagulation - Managing Radioactive Residuals	Allen Water Filtration Plant	Englewood, Colorado	48,000	8.5	Surface Water (river, creek, diversions)	B-33	3.7

Case Study No.	Treatment/Issue Addressed	Utility Name	Case Study Location	Population Served	Average Annual Treatment Plant (MGD) Production	Source Water	Page	Section Where It is Referenced in the Manual
7	GAC for TOC Removal	Higginsville Water Treatment Plant	Higginsville, Missouri	<10,000	2	Surface Water (reservoir)	B-39	4.1
8	Nanofiltration Membrane Technology for TOC Removal	PBCWUD Water Treatment Plant #9	West Palm Beach, Florida	132,000	27	Ground Water (surficial aquifer)	B-43	4.3
9	Modifying Chloramination Practices to Address Nitrification Issues	Ann Arbor Utilities	Ann Arbor, Michigan	115,000	20	Surface Water (river, wells)	B-51	5.1
10	Ozonation	Ann Arbor Utilities	Ann Arbor, Michigan	115,000	20	Surface Water (river, wells)	B-57	5.2
11	Ozonation and Biological Filtration	Sweeney Water Treatment Plant	Wilmington, North Carolina	75,000	25	Surface Water (river)	B-65	5.2
12	UV Disinfection	Poughkeepsie Water Treatment Facility	Poughkeepsie, New York	75,000	16	Surface Water (river)	B-71	5.3
13	Chlorine Dioxide for Primary Disinfection and Chloramines for Secondary Disinfection	Gulf Coast Water Authority	Texas City, Texas	92,000	12	Surface Water (river)	B-75	5.4

Case Study No.	Treatment/Issue Addressed	Utility Name	Case Study Location	Population Served	Average Annual Treatment Plant (MGD) Production	Source Water	Page	Section Where It is Referenced in the Manual
14	Chlorine Dioxide for Primary Disinfection and Chloramines for Secondary Disinfection	Village of Waterloo Water Treatment Plant	Waterloo, New York	<10,000	2	Surface Water (lake)	B-81	5.5

Exhibit 2.6 Tools for Gathering System-Specific Information on Different Compliance Techniques

Compliance Techniques	Water Quality Monitoring	Hydraulic and WQ Modeling for DS	Desktop Evaluation	Bench-Scale: Disinfectant Demand and Decay	Bench-Scale: DBP Formation and Decay	Bench-Scale: Taste and Odor Profiles	Bench-Scale: Jar/Column Testing Procedures	Bench-Scale: Internal Corrosion Assessment	Pilot Testing	Full Scale Applications	Cost Estimation	Community Preferences	Where it's discussed in more detail
Source Management	X		X				X				X	X	Section 3.1
Distribution System BMPs	X	X	X							X	X	X	Section 3.2
Moving the Point of Chlorination Downstream	X	X	X	X	X		X		X	X	X		Section 3.3
Decreasing pH	X	X	X	X	X		X	X	X		X		Section 3.4
Decreasing Chlorine Dose Under Warm Water Conditions	X		X	X	X					X	X		Section 3.5
Presedimentation	X		X							X	X		Section 3.6
Enhanced Coagulation	X	X	X				X	X	X	X	X		Section 3.7
Softening/Enhanced Softening	X	X	X		X		X	X	X	X	X		Section 3.8
GAC	X	X	X				X		X	X	X		Section 4.1
Microfiltration/Ultrafiltration	X	X	X				X		X	X	X		Section 4.2
Nanofiltration	X	X	X					X	X	X	X		Section 4.3
Other Microbial Removal Technologies including Bank Filtration	X	X	X						X	X	X		Section 4.4
Chloramines	X		X	X	X	X		X	X		X	X	Section 5.1
Ozone	X		X	X	X	X		X	X		X	X	Section 5.2
UV Disinfection	X		X						X	X	X		Section 5.3
Chlorine Dioxide	X		X	X	X	X		X			X	X	Section 5.4

3 Improving and Optimizing Current Operations

Public water systems (PWSs) will generally find that improving and optimizing current operations is the best first step as they consider changes to ensure continued compliance with LT2ESWTR and Stage 2 DBPR. There are several reasons for this.

- Operational changes to optimize existing processes can often achieve significant reductions in DBPs and pathogens, improve disinfection, and improve water quality without major capital improvements. These changes may be enough to achieve compliance;

- Operators are familiar with existing processes, which will simplify the transition;

- Even if improving and optimizing current operations does not get a system in compliance by itself, it may allow for the use of a less expensive or simpler technology to ensure compliance; and

- If existing technologies are not optimized, adding a new technology may not have the desired effect or may cost more to operate.

OPERATIONAL PRACTICES COVERED IN THIS CHAPTER

- **Source Management**
- **Distribution System Best Management Practices**
- **Moving Point of Chlorination**
- **Modifying pH During Chlorination**
- **Modifying Chlorine Dose Under Different Temperature Conditions**
- **Modifying Pre-sedimentation Basin Operations**
- **Enhanced Coagulation**
- **Enhanced Softening**

This chapter addresses ways that water systems might change how they operate their existing facilities to achieve compliance with the Stage 2 DBPR and LT2ESWTR. These changes can be made individually or in combination to improve and optimize current operations as a whole. Improving filter turbidity performance is in Chapter 4 instead of this chapter because of the similarity of issues between this option and other filtration options included in Chapter 4.

Several options described in this chapter are ways in which water systems might modify their existing chlorination practices. Before making any significant changes to disinfection practices, systems that are required (by the IESWTR, LT1ESWTR, and LT2ESWTR) to develop a disinfection profile must calculate a disinfection benchmark for the treatment configuration currently in place. To learn more about disinfection profiling and benchmarking, refer to EPA's *Disinfection Profiling and Benchmarking Guidance Manual* (1999a).

3.1 Source Management

For the purpose of this guidance, the term ***source management*** refers to techniques that water systems can use to manipulate their water source or sources to comply with Stage 2 DBPR or LT2ESWTR regulations. In this context, source management does not refer to source water protection or other long-term watershed efforts to improve water quality. The source management techniques discussed in this section are operational changes made by water systems to use the source with the least amount of contaminants, such as pathogens and natural organic matter (NOM), or selecting a blend of sources to try to achieve the most effective treatment for organics and turbidity removal. Examples of source management include:

Water system managers should check with their primacy agency before making any source management changes. Approval of the primacy agency may be required before a water system modifies or switches its raw water source.

- Selecting the optimum depth from which to draw water. Systems using lake or reservoir sources should have multi-level intakes. This flexibility allows the system to draw water from different depths or locations, depending on the source water quality during that time of year or for other reasons (e.g. algal bloom, storm upsets, etc);

- Blending various sources. Systems that have multiple sources may consider blending surface and ground water sources to attain the best blended raw water for compliance. If blended prior to treatment, all water must be treated to surface water standards;

- Alternating between sources. Systems with multiple sources may consider alternating between surface water and ground water sources depending on source water quality at a given time. Systems may also temporarily discontinue use of a source for a period of time when negative impacts are expected or water quality is poor; and

- Using the optimum intake. Systems may have more than one intake they can use to draw from a source. By determining the intake with the highest water quality for each particular time period, the system can obtain the optimum water quality year round.

Many systems have one or more source management options available to them, while others have limited opportunities to manage their source water quality in this way. Those systems that think they could benefit from greater source management flexibility are encouraged to diversify their options as feasible when they are planning capital improvements.

Source management may be considered as a temporary, seasonal, or permanent solution depending on physical or chemical characteristics of the source; the need to reduce disinfection byproduct (DBP) precursors, *Cryptosporidium* and/or turbidity; the availability of alternate, additional, or new sources; and the impact the water chemistry change has on the rest of the system. For example, a system may only have seasonal issues with DBP precursor concentrations and, therefore, may decide to apply one or more source management techniques on a seasonal basis.

Many factors can have a temporary or seasonal impact on surface water quality and can impact organic loading, turbidity, and pathogen concentrations entering the plant. If these impacts are understood and flexibility is built into the plant intake and operations, the system may be able to use source management strategies to comply with the Stage 2 DBPR and LT2ESWTR and avoid or mitigate simultaneous compliance issues. These factors include:

- Seasonal turnover - In colder climates many reservoirs and lakes experience turnover during the spring and fall. When this occurs, sediment, organic matter and particulates at the bottom of the reservoir can be stirred up and re-suspended. This can lead to an increase in organic load, algal blooms causing taste and odor, turbidity, and higher pathogen concentrations entering the plant;

- Precipitation events - Heavy rainfall or snowmelt can wash organic matter and particulates from soils into surface water sources. A runoff event upstream of the intake can result in an increase in organic load and pathogens entering the plant;

- Algae blooms - Seasonal algae blooms that occur in lakes and reservoirs can impact NOM levels and raw water pH in water nearer to the surface. Decayed algae can contribute organics to sediment that later become problematic during turnover. Algae blooms can also interfere with filter operation and may interfere with analysis for *Cryptosporidium* and *Giardia*;

- Point source discharges - Discharges from wastewater treatment plants, water treatment plants, and industrial discharges upstream of the intake can increase the organic load and pathogens in source water. This becomes more significant when stream flow decreases and there is less dilution; and

- Nonpoint sources of pollution - Nonpoint discharges of pollution can impact the organic load in the source water. They can also increase microbial contaminants such as *Cryptosporidium* and increase nutrients that can cause algal blooms. Many such sources of pollution are intermittent or seasonal and, if the system is aware in advance, adverse impacts can be avoided by temporarily discontinuing use of the source.

If a ground water is used to supplement a surface water source on a seasonal basis, the quality of the ground water should be considered, including its pH, iron and manganese concentrations, oxidation reduction (redox) potential of the water, and any nearby contaminant plumes.

3.1.1 Advantages of Source Management

By using source management techniques, a PWS may be able to:

- **Reduce DBP precursors in the raw water (reduction in raw water organic load);**
- **Reduce turbidity or pathogen levels in the raw water;**
- **Reduce oxidant or chlorine demand in the raw water and amount of disinfectant used; and**
- **Improve treatability of raw water for turbidity and/or DBP precursors.**

While changes to the source may be advantageous for minimizing DBP precursor concentrations or turbidity, any major changes in the source water entering plants are likely to be accompanied by corresponding changes in other raw water chemistry. These may include changes in pH, temperature, alkalinity, organics, inorganics, radionuclides, etc. As a result, these changes will have an impact on the treatment processes employed by the system and may impact the distribution system as well. Therefore, when a source water change is considered, water quality monitoring and jar testing should be conducted to determine the impacts the change in water chemistry will have on the plant, as well as the stability of the distribution system. Some, but not all of these are included in Section 3.1.2.

Jar testing should be conducted when a system is considering a source water change.

Reduce DBPs

Selecting a source water or combination of source waters containing the least amount of or more treatable organic matter can reduce finished water DBP concentrations. The water chemistry of stratified lakes and reservoirs can change seasonally and vary significantly depending on water depth. Different depths in a stratified source may contain different concentrations of organics with different characteristics (e.g., particulate vs. dissolved, high vs. low molecular weight). Water systems can use this to their advantage by determining the depth containing the lowest DBP precursor concentrations or precursors that are most easily removed, and then draw their source water from this depth. Systems should keep in mind, however, that the depth producing the lowest concentration of DBP precursors may change seasonally. It is important for an effective source management program to include routine monitoring to detect changes in water quality at different intake depths and guide decision-making. Section 3.1.3 provides some suggestions for additional monitoring that can help in this way.

Blending sources can also produce lower finished water DBP concentrations if the additional source used in blending contains lower concentrations of DBP precursors.

Reduce turbidity or pathogen level

Routine reservoir monitoring can help a system select the best intake depth for minimizing DBPs.

Turbidity and pathogen concentrations can vary depending on the location, timing, and characteristics of the particles or pathogens. For example, stratified reservoirs can have different turbidity levels at different elevations, especially during algae blooms. Certain pathogens can also concentrate in one location of a reservoir. By being aware of the concentrations of particles and pathogens at various locations in the water source the system can plan its withdrawals to minimize the concentrations of these contaminants.

Reduce Amount of Disinfectant Used

Organic matter, inorganic matter, and biota such as algae in water usually present a chlorine demand. If an alternative water source is used that is well-oxygenated and has lower concentrations of organic matter, iron, and manganese, the water is likely to have a lower chlorine demand than the poorer quality water previously used.

Raw Water Treatability

By drawing water from different depths in a stratified source, blending sources or alternating sources, the raw water chemistry may also be manipulated to provide optimum conditions for water treatability resulting in increased particulate removal. For example, systems that have minimal alkalinity in the source water may find that blending another source water with higher alkalinity may improve coagulation (when using alkalinity-dependent coagulants), resulting in a reduction in DBP precursors and turbidity. In this situation, however, systems should keep in mind that increasing alkalinity would in turn increase the amount of chemical needed to lower the pH and effectively remove total organic carbon (TOC).

Different types of organic matter in water can be removed more or less effectively during coagulation. In general, water containing primarily non-humic organic matter is less amenable to enhanced coagulation. This type of water is also more likely to have a lower specific ultraviolet absorbance (SUVA) concentration. By monitoring for NOM indicators such as SUVA in their source water alternatives, water systems can pick the water that can be treated more effectively for NOM removal and, possibly, reduce DBP concentrations in the finished water.

By avoiding water with algal blooms, systems can improve the coagulation properties of the water. Avoiding algal blooms can also reduce taste and odor compounds that are difficult to remove during conventional treatment.

3.1.2 Potential Operational and Simultaneous Compliance Issues Associated with Source Management Changes

Any changes to the raw water as a result of source management are likely to affect the raw water chemistry and in some way impact treatment processes. While the goal may be to minimize organic and/or pathogen loading or provide optimum conditions for DBP precursor and turbidity removal, adverse changes in the raw water chemistry may include:

- **Water temperature changes affecting CT (concentration × contact time) calculations and coagulation and flocculation;**

- **Introduction of new contaminants or higher concentrations of existing contaminants (e.g., iron, manganese, sulfide);**

- **Variation in raw water pH adversely affecting water treatment;**

- **Reduction in coagulation effectiveness or increased coagulant demand because of other chemistry changes (e.g., alkalinity, type of turbidity);**

- **Changes in source water quality impacting corrosion control effectiveness;**

- **Increased disinfectant demand for water under reduced conditions (e.g., little or no dissolved oxygen); and**

- **Changes in aesthetic quality may generate customer complaints.**

Again, as noted in section 3.1.1, water quality monitoring should be conducted to determine the impacts of changes in water chemistry. Section 3.1.3 lists additional parameters that systems can monitor to guide their source management decisions. General suggestions for addressing some of these issues that may arise as a result of source changes are provided below.

Changes in Water Temperature

If a water system's managers opt to draw from a lower level in a thermally stratified reservoir during warmer months in order to decrease DBP precursors at the plant, the water temperature may be considerably lower than the system typically experiences. It is not unusual in northern parts of the U.S. for water temperatures near the top of a reservoir to be at least 10 degrees C higher than temperatures near the bottom. As water temperature decreases, pathogen inactivation using most disinfectants is less effective, and therefore the required CT must be increased. Since the system’s contact time (T) is generally set, the disinfectant concentration (C) may need to be increased when operating at maximum capacity. Therefore, the benefit gained by changing the source to one with lower DBP precursors may be offset by the required increase in disinfectant concentration, and little gain in terms of reducing finished water DBPs may be realized. Alternatively, the lower temperature may slow down DBP formation reactions and residual decay reactions that may mitigate the effect of temperature to some degree.

The converse, however, may also apply. If a system draws from a higher level in the reservoir and there is a corresponding higher temperature, this may result in more efficient inactivation and therefore less required CT.

Colder water temperatures also result in slower floc formation in the coagulation process and therefore, decreased efficiency of turbidity removal (Faust and Aly 1998).

Recommendations for Addressing this Issue

Systems may need to increase their CT when using a colder water source. Frequently a system's T is set, especially when a system is operating at maximum capacity in the summer months. Therefore, the disinfectant residual concentration may need to be increased in the treatment plant.

Changes in temperature may require changes in coagulant dose, mixing speeds, and other factors related to coagulation. To determine the impact colder water temperature may have on the coagulation process, systems should conduct jar tests with the modified source water to determine optimum conditions for coagulation based on the new water temperature and chemistry. As the source water temperature and/or water chemistry changes, additional jar tests should be conducted to determine the optimum conditions based on the new temperature or water chemistry change.

Introducing New Contaminants or Higher Concentrations of Existing Contaminants

Contaminants such as arsenic, dissolved iron, dissolved manganese, or hydrogen sulfide may be introduced or their concentrations may be increased depending on source management decisions. For example, in the summer months a system may alternate its surface water source with a ground water source to produce water lower in DBPs. This may, however, introduce contaminants into the source water for which there is not adequate treatment in place for removal, or the contaminant may deplete chemicals used in the treatment process that are needed for other purposes (e.g., dissolved iron may deplete chlorine meant to be used for disinfection). For systems using thermally stratified sources, drawing from a lower depth to avoid high turbidities may introduce water with higher concentrations of dissolved organics or soluble metals.

Another potential problem with a system introducing new contaminants or contaminants at higher concentrations is the potential for increasing contaminant concentrations in the residual waste streams of certain treatment processes. For example, if higher arsenic concentrations are introduced in a conventional surface water plant, the arsenic will be oxidized and removed, and will be concentrated in the sludge and backwash water.

Recommendations for Addressing this Issue

To address the problem of introducing or increasing contaminant concentrations in the source water, systems should analyze the water chemistry of the alternate source for typical constituents and suspected contaminants. Systems can then compare the alternate source's water chemistry with the original source and consider the possible impacts prior to making source changes. Section 3.1.3 provides some suggestions for additional monitoring to assist with this decision making process. Once the new source water chemistry has been characterized, systems using coagulants should conduct jar tests to determine if contaminant concentrations negatively impact the treatment process. Several tests may be necessary to determine a source management option that works best for meeting all treatment goals.

Problems with a Change in Raw Water pH

A water system may change its source to decrease DBP precursors at the plant, but the change may also affect the pH of the raw water. Variations in raw water pH will affect CT, coagulation effectiveness for certain coagulants, and possibly DBP formation, unless pH is controlled ahead of and through the treatment plant.

For systems that use chlorine to disinfect, pathogen inactivation is very dependent on pH. As pH increases, inactivation is less efficient, and therefore the required CT must be increased. Since the system's contact time is frequently set, the disinfectant concentration (C) may need to be increased when operating at maximum flow. As with the impact from temperature, the benefit gained by changing the source to one with lower precursors may be offset by the required increase in disinfectant concentration. Under these circumstances, little gain may be realized.

Variations in the raw water pH can affect the coagulation process. The pH may no longer be in the optimum range for coagulation using pH-dependent coagulants such as alum. Less effective coagulation is likely to result in less DBP precursor removal, leaving more DBP precursors available for reaction with chlorine or other disinfectants downstream in the treatment process. If the pH of the source water is low and alum is used for coagulation, aluminum ions may pass through the filters if alum is overdosed. A more detailed discussion of aluminum solubility can be found in section 3.4.2.

Recommendations for Addressing this Issue

If the source water pH changes, water systems should conduct jar tests to determine optimum coagulation/flocculation conditions based on the new pH. Systems should ensure that corrosion control is adjusted accordingly if the pH change persists in water entering the distribution system.

Reduced Coagulant Effectiveness

If source management is used to reduce DBP precursors, the turbidity of the raw water may increase as a result. An increase in turbidity may result in increased coagulant demand and, possibly, increased alkalinity demand. Water with increased turbidity may be more difficult to treat, especially for systems that are not optimized or are nearing the design capacity of the coagulation process. Higher influent turbidity can also lead to higher settled water turbidity and problems with filtration.

Recommendations for Addressing this Issue

Systems should characterize the source water chemistry of the proposed new source or blend of sources to ensure there are no negative impacts related to the coagulation process. Jar tests should be performed if parameters that impact coagulation such as turbidity, alkalinity, pH, or temperature change significantly.

Changes in Corrosion Control Effectiveness

Systems using source management options such as blending various sources or alternating between sources may experience changes in source water quality. This is especially true for systems that switch from ground water to surface water, or vice versa. Fluctuations or permanent changes to source water quality may impact the effectiveness of existing corrosion control practices.

Recommendations for Addressing this Issue

Systems should characterize the source water chemistry of the proposed new source or blend of sources to evaluate the impact of dissimilar waters on corrosion control. Systems may need to make changes to their corrosion control process if there are differences in water quality.

Increased Disinfectant Demand for Waters under Reduced Conditions

When drawing from lower reservoir depths or from ground water sources, the water may be under reduced conditions (with low or no dissolved oxygen (DO)). Dissolved iron, manganese, and hydrogen sulfide may be present in these waters. The dissolved oxygen level at which these agents become a problem is site specific and depends on other water quality parameters such as pH and iron speciation. These reducing agents are readily oxidized by disinfectants and, therefore, increase the disinfectant demand. In addition, dissolved iron and manganese precipitate when oxidized, creating more turbid water and increasing the particle load onto the filters.

Recommendations for Addressing this Issue

Water systems should be aware of the DO concentration and oxidation reduction potential of the source water they are using. Chlorine dose should be adjusted to accommodate the increased chlorine demand due to reduced conditions. Alternatively, systems may consider periodic use of an additional oxidant, such as potassium permanganate, as a pretreatment to oxidize reduced iron, manganese, or sulfide (Cooke and Kennedy, 2001). Aerating the water before it is treated can be another effective way to eliminate reduced conditions.

Once they are oxidized, the inorganic chemicals that were formerly dissolved are likely to precipitate. Water systems should carefully review their filter effluent turbidities to ensure that additional particle loading is not stressing the filters. Systems should also conduct jar tests to determine how to adjust their coagulant dose to improve removal of the additional particle load.

Changes in Aesthetic Quality May Generate Customer Complaints

When drawing from lower reservoir depths or changing to a groundwater source, systems may draw in hydrogen sulfide, iron, manganese and other compounds that may cause taste and odor problems. An increase in hardness may also generate customer complaints.

Recommendations for Addressing this Issue

Systems that draw from anoxic layers in stratified reservoirs or from anoxic groundwater may want to add a pre-oxidant to oxidize compounds such as iron, manganese, and hydrogen sulfide (Cooke and Kennedy, 2001). Changes in hardness should be considered and lowered if they become problematic by blending sources or by softening processes. Some systems may want to notify customers of a source water change to explain why they may be seeing a change in water characteristics at the tap.

3.1.3 Recommendations for Gathering More Information

See Additional References

Readers can turn to Section 7.1.4 in Chapter 7 for technical references associated with source management.

Consider Additional Monitoring

Source management changes are likely to affect raw water chemistry. Additional monitoring can help systems understand how treatment processes and other components of a PWS will be affected by changes in the raw water chemistry. Water quality monitoring can also be used for making source management decisions. For example, a system that monitors water quality at its various intake depths can use measurements such as turbidity or TOC to decide which intake gates to open and use. Many of these parameters can be monitored in real time to provide immediate feedback into plant operation.

Systems choosing to use any of the source management options discussed in this section should consider monitoring the applicable following parameters at a location before water enters the treatment plant:

- ✓ Dissolved Oxygen
  - Ground water and stratified surface water sources
  - DO profiles of lakes or reservoirs at the intake location using a field meter

- ✓ Temperature
  - All sources
  - Temperature profiles of lakes or reservoirs at the intake location using a field meter

- ✓ pH
  - All sources
  - pH profiles of lakes or reservoirs at the intake location using a field meter

- ✓ Secchi disk depth
  - Lakes and reservoirs to determine water clarity

- ✓ Oxidation-reduction (redox) potential
  - Ground water and stratified surface water sources using a field meter, if possible

- ✓ Turbidity
- ✓ Alkalinity
- ✓ NOM measured as TOC or SUVA
- ✓ Dissolved iron
- ✓ Dissolved manganese
- ✓ Hydrogen sulfide
- ✓ Other chemicals known to be problematic for ground or surface water sources in the area
- ✓ Chlorophyll *a* and algal counts

Consider Other Tools

In addition to water quality monitoring, there are multiple tools available in Chapter 6 to help systems evaluate and improve their current water system in relation to the compliance issues they may face when modifying their operation or treatment practices. For example, the AwwaRF report "Design of Early Warning and Predictive Source-Water Monitoring Systems" (Grayman et al. 2001) provides guidance on the development of source water quality monitoring systems that allow utilities to predict water quality events in the source water.
Readers are encouraged to read through Chapter 6 before making any final compliance decisions.

3.2 Distribution System Best Management Practices

The overall objectives of distribution system best management practices (BMPs) are to maintain the quality of the treated water while also meeting water quantity, pressure, and service reliability goals. If there is a significant increase of DBP concentrations from the finished water to the distribution system, systems should consider implementing BMPs to lower DBP levels in the distribution system. BMPs that can be particularly effective in reducing DBP formation in the distribution system include:

- Water age management strategy
- Booster disinfection
- Water main flushing program

Other BMPs that are important for overall management of distribution system water quality include but are not limited to a pressure management strategy, backflow prevention program, procedures to prevent contamination during installation and repair of water mains, a pipeline rehabilitation and replacement program, and finished water storage facility inspection and cleaning program. These BMPs are also discussed briefly below.

Water systems should prioritize the implementation of BMPs based on their system conditions and needs. BMPs are particularly important for systems purchasing water from other systems because the purchasers normally have limited flexibility for improving the water quality entering the distribution system. Some systems may face operational and simultaneous compliance issues when implementing distribution system BMPs, as discussed later in this section.

Water Age Management Strategy

As water travels through the distribution system, chlorine continues to react with NOM to form DBPs. Thus, increased water age can lead to higher DBP concentrations[1]. Other water quality problems associated with increased water age include reduced disinfectant residual, increased microbial activity, nitrification, and/or taste and odor problems.

Water systems should develop an overall strategy to manage the water age in their distribution systems. Establishing a water age goal is system-specific depending on system design and operation, water demands, and water quality (e.g. DBP formation potential). In the US, the average distribution system retention time is 1.3 days and the average maximum retention time is 3.0 days based on a survey of 800 medium and large water utilities (AWWA and AwwaRF 1992).

Water age can be controlled through a variety of techniques including management of finished water storage facilities, looping of dead-ends, and re-routing of water by changing valve settings. Additional guidance is provided in the AwwaRF report, *Managing Distribution System Retention Time to Improve Water Quality* (Brandt et al. 2004).

- **Improve Mixing in Storage Facilities.** Improving mixing in finished water storage facilities can help eliminate stagnant zones. Old water in stagnant zones can often have very high DBPs and no or low disinfectant residual. This water can be released into the system during periods of high demand. Mixing can be improved by increasing inlet momentum, changing the inlet configuration, increasing the fill time, and by installing mixing devices within the storage facility. Hydraulic experts should be consulted to determine which of these strategies will work for a given tank design and configuration. Additional information is provided in an AWWA publication, *Physical Modeling of Mixing in Water Storage Tanks* (Roberts et al. 2006).

- **Minimize the Hydraulic Residence Time in Storage Facilities.** Increasing volume turnover reduces the average hydraulic residence time (HRT) in finished water storage facilities, thereby reducing DBP formation, loss of disinfectant and microbial growth. Kirmeyer et al. (2000b) recommend a

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[1] The extent of DBP formation in the distribution system is dependent on many factors and is site-specific. TTHM levels typically increase with water age. Because HAA5 can biodegrade, however, HAA5 concentration may decrease with advanced water age in areas of the distribution system with low or non-detectable disinfection residuals and increased microbial activity. See Section 7.1.2 for references on DBP formation.

complete turnover every three to five days but suggest that water system's establish their own turnover goal based on system-specific needs and goals. Turnover can be accomplished by increasing the water level fluctuation or drawdown between fill and draw cycles. The water level should be lowered in one continuous operation not small incremental drops throughout the day. Converting tanks to eliminate common inlet/outlet configurations can also reduce average HRT.

- **Decommission Storage.** Decommissioning storage facilities may be an appropriate strategy to reduce water age if existing facilities are oversized and not needed for emergency conditions, fire protection, or for maintaining system pressure. A professional engineer should review system needs, system design, and operation to determine if the existing storage capacity is appropriate.

- **Minimize Hydraulic Residence Time in Pipes.** Minimizing the HRT in pipes can help reduce the time available for DBP formation, although it is possible for an increase in HAA5 to occur because of less biological degradation. Reducing HRT can also minimize disinfectant residual loss and allow systems to use a lower overall residual concentration, thereby reducing DBPs. Systems can reduce HRT and disinfectant loss through physical system improvements such as looping dead ends, installing blow-offs, and replacing oversized pipes. These can be expensive, however, and cost-prohibitive for some systems.

Booster Disinfection

Booster disinfection can improve disinfectant residual maintenance and minimize formation of DBPs by allowing systems to reduce the chlorine residual leaving the treatment plant and feed chlorine at select locations in the distribution system to maintain a residual. Systems can reduce the booster disinfectant dosage rate by first reducing the disinfectant demand within the piping system through various maintenance programs. For example, periodic flushing of the water mains removes loose sediment. Cast iron pipes can be cleaned and lined with materials that are less prone to microbial growth or have less potential for consuming oxidants.

Develop and Implement a Water Main Flushing Program

A water main flushing program helps to keep the system clean and free of sediment, reduces the disinfectant demand of pipe surfaces, and removes stagnant water and any untreated or contaminated water that enters the system (Kirmeyer et al. 2000b). Flushing can also be used to address water quality deterioration at dead-ends. If a dead-end is unavoidable, industry and regulatory guidance recommend fitting dead-ends with hydrants or blow-offs for flushing purposes (Friedman et al. 2005).

Minimum elements of a flushing program are outlined in the AWWA G200 Standard (AWWA 2004e) and include: (1) a preventive approach including spot flushing to address local problems or customer concerns and routine flushing to avoid water quality problems; (2) use of an appropriate flushing velocity to address water quality concerns; and (3) written procedures for all elements of the flushing program including water quality monitoring, regulatory requirements and specific flushing procedures.

Kirmeyer et al. (2000b) developed an approach to assist utilities with developing, implementing, and evaluating the effectiveness of flushing programs. The program includes four steps:

- **Step 1: Determining the Appropriateness of Flushing as Part of a Utility Maintenance Program.** In this step, the water system conducts a self-assessment to determine if flushing is needed to maintain distribution system water quality and what type of flushing is warranted. For example, yes answers to the following questions would indicate a need for flushing:

  - Do you experience frequent water quality-related customer complaints?
  - Do you have difficulty maintaining a disinfectant residual in portions of the distribution system?
  - Does sediment accumulate in finished water storage facilities?

  If the water system determines that flushing is needed, a second self-assessment can help determine the feasibility of conducting an effective flushing program. Questions to consider prior to initiating flushing may include:

  - Will hydraulic constraints prevent the achievement of desired flushing velocities?
  - Is enough water available to flush at desired velocities for desired duration?
  - What are the requirements for disposing of the water?

- **Step 2—Planning and Managing a Flushing Program.** In this step, the water system identifies flushing objectives, determines the most effective flushing approach, and establishes specific flushing procedures. Flushing objectives may involve both water quality considerations as well as hydraulic and maintenance considerations. One or more flushing approaches may be appropriate, unidirectional, conventional, and/or continuous blow-off depending on system configuration and flushing objectives. Each approach can be implemented on a comprehensive, system-wide basis or on a more limited “spot” basis. Other important planning activities include notifying customers of flushing activities and identifying sensitive users that may be impacted by temporary water quality changes as a result of flushing;

- **Step 3—Implementing a Flushing Program and Data Collection**. Water quality monitoring and documentation of costs provide information needed to evaluate the program (Step 4); and

- **Step 4—Evaluating and Revising a Flushing Program.** Kirmeyer et al. (2000b) suggest that experimenting with flushing velocities, duration, and frequency may help the water system establish a flushing program that meets water quality goals within their operating budget. Additional guidance is provided in an AwwaRF report, *Cost and Benefit Analysis of Flushing* (DeNadai et al. 2004).

Care should be taken regarding disposal of disinfected water. The AwwaRF report *Guidelines for the Disposal of Chlorinated Water* (Tikkanen et al. 2001) provides strategies for removing chlorine and choramine from water during flushing. See Section 3.2.3 for additional information.

In some cases, flushing may not be adequate to clean water mains. Techniques such as pigging may be needed to remove accumulated material.

Other BMPs for Maintaining Distribution System Water Quality

- **Pressure Management Strategy.** Pressure losses can occur in the distribution system as a result of events such as flushing, main breaks, power outages, service line breaks, and fires. Pressure transients (also called pressure surges or water hammer) can occur when an abrupt change in water velocity occurs, due to a sudden valve closure, pump shutdown or loss of power. The resulting pressure wave, with alternating low and high pressures, travels back and forth through the distribution system until the pressure is stabilized. Low pressure conditions in the distribution system can allow a flow reversal or backflow of non-potable water to enter the system from a cross connection or other source. Pressure transients can also create hydraulic disturbances that allow biofilm material on pipe surfaces to enter the bulk water. Industry guidelines suggest that system pressure should be maintained within the range of 35 to 100 psi at all points in the distribution system (AWWA 1996). The AWWA G200 standard indicates that the minimum residual pressure at the service connection under all operating conditions should be $\geq$ 20 psi (AWWA 2004c). Written standard operating procedures for pump, hydrant and valve operation under routine and emergency conditions can help minimize sudden changes in water velocity that impact system pressure;

- **Backflow Prevention Program.** The National Research Council (2006) ranked cross connections and backflow events as the highest priority concern for water distribution systems. Systems should have cross connection control and backflow prevention programs that meet state regulatory requirements and adhere to industry guidelines (AWWA 2004c);

- **Program to Prevent Contamination During Installation and Repair of Water Mains.** Contamination of the distribution system following water main breaks or new installations was identified as a high priority issue by the National Research Council (2006). The AWWA Standard C651-05 (AWWA 2005c) provides a method for disinfecting newly constructed water mains or water mains that have undergone repairs. Pierson et al. (2001) developed comprehensive best practices to prevent microbiological contamination of water mains covering topics such as site conditions; condition and storage of materials; general construction/repair practices; preparing for service; and project closeout;

- **Pipeline Rehabilitation and Replacement Program.** A comprehensive program to assess and upgrade water mains will help maintain water quality and to provide reliable service. Pipe replacement and various types of pipe lining can help improve water quality as well as increase carrying capacity of pipes. AWWA Standard G200 (AWWA 2004c) and several AwwaRF publications provide guidelines for program elements; and

- **Finished Water Storage Facility Inspection and Cleaning Program.** Regular inspection of storage facilities provides information needed to plan facility maintenance and to minimize contaminant entry to the system. Kirmeyer et al. (2000b) identifies three types of inspections - routine, periodic and comprehensive. Routine inspections, conducted on a daily to weekly basis, are primarily a visual inspection of the tank's structural integrity and the site's security. Periodic inspections, conducted every one to four months, require climbing the tank to visually inspect areas not normally accessible from the ground. Comprehensive inspections are conducted every three to five years depending on state requirements and industry guidelines. Comprehensive inspections evaluate the structural condition of storage facility components including interior features. Kirmeyer et al. (2000b) recommends that covered facilities be cleaned every three to five years, and uncovered storage facilities be cleaned once or twice per year. The cleaning frequency should be set based on system-specific information such as inspection reports and water quality monitoring data.

3.2.1 Advantages of Distribution System BMPs

Depending on treatment and distribution system configuration and characteristics of DBP formation, distribution system BMPs may be less expensive ways to achieve compliance with the Stage 2 DBPR compared to advanced treatment options. Other advantages to implementing distribution system BMPs include:

- **Target specific problem areas**
- **Improve microbial control**
- **Improve chlorine residual maintenance**
- **Reduce corrosion**
- **Reduce nitrification**

Target Specific Problem Areas

Many of the BMPs such as flushing, booster disinfection, and management of finished water storage facilities can target specific problem areas rather than apply a solution to the entire system. This is an efficient way to improved water quality in the distribution system.

Improve Microbial Control

In additional to reducing DBP formation, most BMPs will improve microbial control by helping to maintain a disinfectant residual and/or reducing biofilms and sediments that encourage biological growth. Improved microbial control can result in fewer Total Coliform Rule violations, fewer violations of the Surface Water Treatment Rule requirement to maintain a disinfectant residual, and less potential for microbiologically-induced corrosion.

Improve Chlorine Residual Maintenance

The National Research Council (2006) ranked loss of disinfectant residual as a medium priority concern for water distribution systems because "…it is an indirect health impact that compromises the biological integrity of the system and promotes microbial regrowth." Long hydraulic residence times, microbial growth, and corrosion products will all deplete the disinfectant residual. The BMPs seek to reduce these factors and will therefore result in higher and more consistent residuals throughout the distribution system.

Reduce Corrosion

Corrosion can cause Lead and Copper Rule compliance problems, aesthetic problems, and may eventually lead to leaks that can be sources of contamination to the system. Corrosion of cast iron pipes can provide a habitat for microorganisms and increase the likelihood of TCR violations. Some BMPs, such as pipe replacement or lining, can reduce corrosion.

Reduce Nitrification

The occurrence of nitrification in chloraminated systems can be reduced through the use of distribution system BMPs. Reducing water age and controlling microbial growth will help reduce nitrification episodes by slowing the decay of chloramines and providing less free ammonia for nitrification.

3.2.2 Potential Operational and Simultaneous Compliance Issues Associated with Distribution System BMPs

Challenges of implementing the BMPs depend largely on the specific BMP. Examples of these challenges include:

- **Re-suspension of sediments**
- **Issues with disposal of disinfected water**
- **Lining materials leaching into the water**
- **Less storage available for emergencies**
- **Increased water loss**

Re-suspension of Sediments

Some BMPs such as increasing storage pumping rates, using blow-offs, or flushing of pipes can cause re-suspension of sediments that had settled in the storage facilities or pipes. These sediments can cause temporary aesthetic complaints and may also contain microbes or particulate metals such as lead, copper, and iron.

Recommendations for Addressing this Issue

A properly implemented flushing program can remove the sediments from the pipes and can result in a positive long-term impact. There are many references listed in the Section 7.1.5, Distribution System Management, that can that can be used to plan, design, implement, and monitor an effective flushing program (AWWA 2002; AWWA 2005b; Kirmeyer et al. 2000b).

Issues with Disposal of Disinfected Water

When flushing water distribution mains or draining storage facilities prior to cleaning or inspections, utilities should be aware of state or local regulations on disposal of chlorinated or chloraminated water. If flushed water flows directly into natural waters, systems may need to remove the disinfectant chemicals prior to discharge to protect the aquatic environment. The National Pollution Discharge Elimination System is a Federal program established under the Clean Water Act, aimed at protecting the nation's waterways from point sources of pollution. Effluent limitations vary depending on receiving water characteristics (use classification, water quality standards, flow characteristics) and discharge characteristics (flow, duration, frequency).

Recommendations for Addressing this Issue

The AwwaRF report, *Guidelines for the Disposal of Chlorinated Water* (Tikkanen et al. 2001) provides information on dechlorination techniques in use by water systems. Some utilities use straightforward field methods such as a bag filled with a de-chlorinating agent placed in the flowing water, while other systems have sophisticated metering and storage equipment installed in trailers.

Lining Materials Can Leach Into Water

Some lining materials can leach chemicals into the water if not properly handled or applied.

Recommendations for Addressing this Issue

It is important to make sure the lining material has been independently certified against NSF/ANSI Standard 61. Manufacturers' instructions and appropriate standards should be followed in lining the pipe and returning it to service as well. In addition to following the certifying agency's and manufacturer's recommendations, many utilities will conduct their own water quality tests for compounds of interest including VOCs and taste and odor-causing compounds before a new lining is returned or released to service.

Less Storage Available for Emergencies

Removing finished water storage facilities from service, while reducing DBPs and improving microbial control, can result in less storage available for emergencies such as drought, earthquakes, main breaks, firefighting, etc. To a lesser extent, some of the other finished water storage BMPs can also reduce the amount of storage available for such events.

Recommendations for Addressing this Issue

Before changes are made to finished water storage, an analysis should be made of system demand and pressure needs and fire flow requirements. This analysis should review appropriate fire ordinances to determine the amount needed. In addition, emergency storage requirements should be addressed. Hydraulic models in combination with source planning can help determine the amount of water to be maintained in storage in various parts of the system. Section 6.3 identifies several hydraulic models that may be helpful.

Increased Water Loss

Flushing programs will lead to a loss of water. This is an added expense and could be troublesome in areas where sufficient water supply is a concern.

Recommendations for Addressing this Issue

The advantages of system flushing often outweigh the cost of lost water. Systems may, however, want to minimize water loss through careful design of the flushing program. For example, Friedman et al. (2003) found that systems that had previously conducted one round of high velocity unidirectional flushing (≥ 5fps) within the last 4-6 years had likely removed all loose, compacted and adhered deposits and may not benefit from additional high velocity flushing. Use of automatic flushing devices may help control flushing volume and reduce water loss. Examining customer complaint and water quality records can help to focus flushing to the areas and times where they are most needed. A public outreach program can help minimize customer perceptions that the utility is wasting water when they observe flushing activities in progress. Additional guidance may be found in an AwwaRF report, *Cost and Benefit Analysis of Flushing* (DeNadai et al. 2004).

3.2.3 Recommendations for Gathering More Information

Read the Case Study

For more information on simultaneous compliance issues associated with distribution system BMPs, see ***Case Study #1 - Improving and Optimizing Current Operations*** starting on page B-5 of Appendix B. This case study describes how two small PWSs with high THM concentrations were able to comply with the requirements of the Stage 1 D/DBPR and Stage 2 DBPR by adjusting their coagulation methods and changing the point of chlorination, while also optimizing distribution operations to minimize water age and optimizing booster chlorine use.

See Additional References

Readers can turn to Section 7.1.5 in Chapter 7 for technical references associated with Distribution System BMPs.

Consider Additional Monitoring

The following are some suggestions for additional monitoring that may benefit water systems implementing distribution system BMPs:

- ✓ Take routine measurements of chlorine residual and heterotrophic plate count (HPC-R2A) in water leaving storage tanks and other distribution system locations with long residence times and in chloraminated systems. Online chlorine analyzers at storage facilities may be helpful;
- ✓ Monitor water quality at dead-end mains. Monitoring parameters may include disinfectant residual, turbidity, coliform bacteria, HPC counts, and DBPs;
- ✓ Increase measurements of total coliform, HPC, chlorine residual, and turbidity in distribution system locations during flushing;
- ✓ Periodically monitor pipe metals (e.g., iron if cast iron pipes are used, lead if lead solder is used) in distribution system regions where corrosion is suspected; and
- ✓ Monitor pertinent chemicals and odor downstream of pipes that have been recently lined or replaced.

The *Stage 2 DBPR Initial Distribution System Evaluation Guidance Manual* (USEPA 2006a) provides distribution system water quality monitoring requirements for the Stage 2 DBPR and can be used to identify locations that tend to have high DBP levels.

The AwwaRF report, “Guidance Manual for Monitoring Distribution System Water Quality” (Kirmeyer et al. 2002), can be used to assist water utilities in implementing a distribution system water quality data collection and analysis program.

Consider Other Tools

In addition to water quality monitoring, there are additional tools available in Chapter 6 to help systems evaluate and improve their current water system in relation to the compliance issues they may face when modifying their operation or treatment practices. Examples of tools that can be used when distribution system best management practices are used for Stage 2 DBPR compliance include:

- Computer hydraulic and water modeling software, such as EPANET (USEPA 2002b), that can be used to simulate hydraulic detention time and water quality in the distribution system; and
- The AWWA manual “Computer Modeling of Water Distribution Systems” (AWWA 2004a) that provides step-by-step instructions for the design and use of computer modeling for water distribution systems.

Readers are encouraged to read through Chapter 6 before making any final compliance decisions.

3.3 Moving the Point of Chlorination

At conventional surface water treatment plants, chlorine can be added for prechlorination at either the raw water intake or flash mixer, for intermediate chlorination ahead of the filters, for postchlorination at the clearwell, or for rechlorination of the distribution system. While inactivation of pathogenic organisms is its primary function, chlorine is used in drinking water treatment for several other purposes, including:

- Control of nuisance Asiatic clams and zebra mussels
- Oxidation of iron and manganese
- Improved coagulation
- Taste and odor control
- Prevention of algal growth in sedimentation basins and filters
- Color removal

Exhibit 3.1 summarizes the typical uses for each point of chlorine application.

Exhibit 3.1 Typical Chlorine Points of Application and Uses

Point of Application	Typical Uses
Raw Water Intake	Zebra mussel and Asiatic clam control, control biological growth
Flash Mixer or Rapid Mix (prior to sedimentation)	Disinfection, iron and manganese oxidation, improved coagulation[1], taste and odor control, oxidation of hydrogen sulfide, algae control
Filter Influent	Disinfection, control biological growth in filter, iron and manganese oxidation, taste and odor control, color removal
Filter Clearwell	Disinfection, disinfectant residual
Distribution System	Maintain disinfectant residual

Source: *Alternative Disinfectants and Oxidants Guidance Manual*, USEPA 1999b.

[1] Not included as a typical use in the above reference, but documented by research

Public water systems with conventional treatment might consider moving the application point for chlorine downstream within the plant to a point after DBP precursors have been removed. Depending on the treatment plant, THM formation potential can be decreased by up to 50 percent as a result of precursor removal during coagulation and sedimentation (Singer and Chang 1989).

3.3.1 Advantages of Moving the Point of Chlorination

By moving the point of chlorination downstream in the treatment process, a PWS can:

- **Reduce DBP concentrations in the finished water**
- **Reduce amount of disinfectant used**
- **Facilitate monthly TOC source water monitoring**

Reduces DBPs

Summers et al. (1996) presented the results from four studies evaluating the impact of pretreatment on DBP formation. Jar tests were conducted to simulate water treatment through rapid mix, coagulation, flocculation, and sedimentation. Chlorine was added at various points in the jar testing to simulate the impact of various dose points on production of DBPs. The results demonstrate the benefits of delaying the point of chlorination downstream in the treatment train to take advantage of precursor removal during flocculation and sedimentation processes. Exhibit 3.2 summarizes the results from this study.

Exhibit 3.2 Percent Reduction in DBP Formation by Moving Point of Chlorination

Chlorination Point	TTHM Baseline (%)	TTHM Enhanced (%)	HAA5 Baseline (%)	HAA5 Enhanced (%)
Pre rapid mix	Baseline	17	Baseline	5
Post rapid mix	2	21	5	21
Mid flocculation	9	36	14	36
Post sedimentation	21	48	35	61

Notes: Source: USEPA 1997 based on Summers et al. 1996
Baseline = Baseline coagulant (alum) dose for optimal turbidity removal (~30 mg/L)
Enhanced = Enhanced coagulant (alum) dose for optimal TOC removal (~ 52 mg/L)

Exhibit 3.2 also includes a comparison of total trihalomethane (TTHM) and haloacetic acid (five) (HAA5) concentrations when enhanced coagulation was used, and the benefits of enhanced coagulation for reducing DBP production. The TTHM formation reduction of 21 percent by moving the chlorination point to post sedimentation is more than doubled to 48 percent by enhanced coagulation. The reduction in HAA5 formation increases from 35 to 61 percent under enhanced coagulation with post sedimentation chlorination. Therefore, DBP control by selecting the optimal dose location and conditions, along with enhanced precursor removal, can significantly reduce DBP formation. For a more detailed discussion of enhanced coagulation and its simultaneous compliance issues, refer to Section 3.7 of this manual.

Reduces Amount of Disinfectant Used

If a system moves its point of chlorination downstream after a significant amount of organic matter has been removed, the chlorine demand of the water will be lower. In some cases, the system may be able to take advantage of the reduced chlorine demand to reduce the overall chlorine dose needed to achieve the required CT. The system would benefit not only in reduced chemical costs, but may also reduce operational costs if they decrease their number of chlorine injection points.

Facilitates Source Water TOC Monitoring

The Stage 1 D/DBPR requires surface water systems (or systems using ground water under the direct influence of surface water) using conventional filtration treatment to monitor each treatment plant for TOC removal. Systems are required to collect TOC samples from the source and the treated water. Source water TOC samples must be collected prior to any treatment, including chlorination.

Some PWSs that are required to conduct TOC sampling prechlorinate at or near the source water intake. These systems currently have to turn off their chlorination in order to collect a proper source water TOC sample. Although it's a minor benefit of moving chlorination downstream in the treatment process, those systems would no longer have to turn off their chlorination in order to collect their source water TOC sample.

3.3.2 Potential Operational and Simultaneous Compliance Issues Associated with Moving the Point of Chlorination

Many PWSs benefit from other functions of prechlorination in addition to its use as a disinfectant. Chlorine can oxidize iron and manganese, improve coagulation, enhance color removal, improve taste and odor, as well as control biological growth at different stages of treatment. Because it has several other functions, some PWSs may find that there are drawbacks to moving the point of chlorination further downstream in the treatment process. Moving the point of chlorination further downstream in the treatment process can:

- **Raise issues with meeting CT requirements**
- **Increase filter fouling**
- **Limit Asiatic clam or zebra mussel control**
- **Limit coagulation and filtration effectiveness**
- **Provide less effective treatment for iron and manganese**
- **Affect pH of water being treated, possibly requiring adjustment of water treatment chemistry**

This section discusses these issues and provides some recommendations for addressing them.

CT Issues

Disinfection effectiveness is measured in terms of CT. If a PWS receives CT credit for contact time prior to filtration and then moves its point of chlorination further downstream in the treatment process, the system will likely have to increase its C to accommodate reduced T. Systems should carefully evaluate their disinfection profiles to ensure that they continue to meet benchmarking requirements. Guidance is provided in the *Disinfection Profiling and Benchmarking Guidance Manual* (USEPA 1999a).

If concentration of disinfectant is increased, high disinfectant residuals may persist into the distribution system. A public water system, however, must maintain disinfectant residual concentrations that meet the MRDL requirements of the Stage 1 D/DBPR. The running annual average (RAA) of the free chlorine residual measured in the distribution system must not exceed the 4.0 mg/L MRDL. Also, if the chlorine residual in the delivered water is increased, the number of customers that will notice a chlorinous odor may increase and generate more frequent customer complaints.

Recommendations for Addressing this Issue

Systems should examine hydraulic conditions and maximize contact time where possible. Clearwells can be modified (e.g., baffling and/or improved inlet and outlet structures added) to improve their hydraulic performance. Constructing additional storage or dedicated disinfection contact basins can also increase CT.

A water system should evaluate the CT that it can achieve downstream of the new application point to ensure that sufficient CT can be maintained once the point of chlorination has been moved. The evaluation should be done for the organism for which the disinfectant is least effective. A system may also want to break up its CT segments into smaller segments. For example, if the section from the raw water intake until the filters had been considered as a single section for performing CT calculations and the point of chlorination is moved until after the flocculation basin, a system can still receive some credit for section between the flocculation basin and the filters. See the *Disinfection Profiling and Benchmarking Guidance Manual* (USEPA 1999a) for more details on calculating CT and using segments. This evaluation should review seasonal impacts on CT (e.g., cold water conditions when higher CT values are needed or if the water’s pH increases during algae blooms in the warmer water months).

If having too high of a residual in the distribution system is an issue a system may be able to extend its contact time instead. Reducing chlorine demand may also help to achieve the required inactivation with a lower chlorine dose.

Potential for Increased Filter Fouling

Prechlorination is often used to minimize operational problems associated with biological growth in water treatment plants. Prechlorination can prevent slime formation on filters, pipes, and tanks, and reduce potential taste and odor problems associated with such slimes. It can also prevent algal growth which can clog filters and cause turbidity problems. Many sedimentation and filtration facilities operate with a small chlorine residual to prevent growth of algae and bacteria in the launders and on the filter surfaces.

Recommendations for Addressing this Issue

If a system is concerned about the potential for algal growth and filter fouling after prechlorination is stopped, there are alternatives the system can consider. If chlorine is being added before the coagulation and flocculation steps, operators may want to consider moving the chlorination point so that it follows these steps but comes before filtration. Adding chlorine immediately before the filters may be an effective way for the system to prevent filter fouling, yet not allow the chlorine to come into contact with the water when the water still contains unsettled DBP precursors (see case study No. 1 in Appendix B).

Adding chlorine immediately before the filters may be an effective way for the system to prevent filter fouling from biological growth.

Systems may be able to eliminate the prechlorination step at certain times of the year, and return to prechlorination when microbial fouling is more likely to occur during the treatment process, such as when there is algal growth in the source water. They may also consider continuing to prechlorinate, but adjusting the prechlorination dose depending on source water conditions or water temperature.

Lastly, a system may consider using an alternative preoxidant, such as potassium permanganate or chlorine dioxide. These oxidants can provide benefits similar to chlorine in terms of iron, manganese, or algae control without forming significant amounts of TTHM or HAA5. They can also reduce chlorine demand before chlorination is applied. Readers should refer to the *Alternative Disinfectants and Oxidants Guidance Manual* (USEPA 1999b) for more information.

Asiatic Clam and Zebra Mussel Control

The Asiatic clam (*Corbicula fluminea*) was introduced to the United States from Southeast Asia in 1938 and now inhabits almost every river system south of 40° latitude (Problem Organisms in Water Treatment: Britton and Morton 1982, Counts 1986). This mollusk has invaded many source waters, clogging source water transmission systems and valves, screens, and meters; damaging centrifugal pumps; and causing taste and odor problems.

The zebra mussel (*Dreissena polymorpha*) population in the United States has expanded very rapidly. Zebra mussels have been found in the Great Lakes, Ohio River, Cumberland River, Arkansas River, Tennessee River, and the Mississippi River south to New Orleans (Lange et al. 1994).

Many PWSs add chlorine at their intakes to control Asiatic clam and zebra mussel growth. For those systems with intakes a significant distance from their treatment plants, prechlorinating for zebra mussel control may allow a substantial amount of time for TTHM or HAA5 formation prior to any precursor removal process.

<u>Recommendations for Addressing this Issue</u>

Asiatic Clams

Systems that add chlorine to control Asiatic clams and have problems with elevated TTHM or HAA5 concentrations may want to consider using an alternative oxidant, such as monochloramine or chlorine dioxide, to control clam growth in their systems. If monochloramine is used, water systems using the monochloramine to also satisfy CT requirements will need to perform a disinfection benchmark, bearing in mind that the CT required for viral inactivation using chloramines is substantially greater than that for chlorine, and should ensure that adequate disinfection is being provided after switching disinfectants.

Monochloramine was found to work well for controlling juvenile clams without forming DBPs.

Cameron et al. (1989) compared the effectiveness of free chlorine, potassium permanganate, monochloramine, and chlorine dioxide for controlling the juvenile Asiatic clam. Monochloramine was found to be the best for controlling juvenile clams without forming DBPs. Further research showed that the effectiveness of monochloramine increased greatly as the temperature increased (Cameron et al. 1989). Belanger et al. (1991) showed that pre-formed monochloramine with excess ammonia was more effective for controlling Asiatic clams than either total residual chlorine, monochloramine, bromine, or copper. Chlorination at 0.25 to 0.40 mg/L total chlorine residual at 20 to 25° C controlled clams of all sizes, but the same dosage had minimal effect at 12 to 15° C.

Zebra mussels

Systems with elevated DBPs may also want to consider using an alternative zebra mussel control strategy. Permanganate has been found to be effective for zebra mussel control and has been used. Chlorine dioxide and ozone have shown promise as effective oxidants that can be used for zebra mussel control. Antifouling coatings can work by slowly releasing into the water a toxic substance, often an organo-metallic compound that prevents the zebra mussel larvae from settling on the pipes. PWSs should check with their State if they are considering a chemical control method, to make sure that the chemical is approved for use in a drinking water supply.

There are many other approaches to zebra mussel control being developed and tested. These methods include:

- The use of electrical fields to kill veligers (zebra mussel larvae)
- Ultrasonic treatment to prevent settlement
- Oxygen deprivation
- Sand infiltration beds
- Thermal control (AWWA 2003c)

In addition, some polymers have been tested recently that show promise.

Coagulation and Filtration Effectiveness

Research has shown that using a preoxidant ahead of coagulation can have a positive effect on coagulation and filtration with respect to particle removal (Becker et al. 2004). By moving chlorination to a point after filtration, a water system may find that it needs to develop new strategies for turbidity and particle control.

Recommendations for Addressing this Issue

Water systems moving chlorination to a point after filtration that can no longer achieve low filter effluent turbidity values or particle counts may want to consider using a preoxidant other than chlorine to improve filter performance. The strongest preoxidants have shown the maximum benefit to filtration, so a system can achieve similar benefits by applying chlorine dioxide or ozone. Systems that choose to do this should consult the Section 5.4 (chlorine dioxide) or Section 5.2 (ozone) of this guidance manual to determine possible effects of these steps.

Iron and Manganese Control

Although not harmful to human health at the low concentrations typically found in water, iron and manganese can cause staining and taste problems. Iron and manganese compounds are treated by oxidation to produce a precipitate that is subsequently removed by sedimentation and filtration. Systems with high manganese levels should also be aware that a manganese coating may have developed on their filters when pre-oxidation was practiced. This layer could dissolve if pre-oxidation is no longer practiced and/or the pH drops (Angara et al 2004).

Recommendations for Addressing this Issue

Systems should be careful to consider how eliminating prechlorination may impact other removal mechanisms during the treatment process. Some may be able to use an alternative oxidant or reduce their prechlorination dose if the chlorine dose required for iron or manganese removal is lower than what is currently being added. The oxidation of iron and manganese can usually be accomplished while maintaining a minimum residual. Potassium permanganate is an effective alternative oxidant to chlorine for iron and manganese oxidation and does not result in TTHM or HAA5 formation. Various alternatives are discussed in greater detail in the *Alternative Disinfectants and Oxidants Guidance Manual* (USEPA 1999b) and the *Guidance Manual for Enhanced Coagulation and Precipitative Softening* (USEPA 1999h).

Problems with a Change in pH

Impacts of pH changes on compliance and operational issues associated with pH are described in Section 3.4.

Moving the point of chlorination or eliminating prechlorination may result in a change in water pH. Adding gaseous chlorine decreases water's pH, whereas adding hypochlorite increases water's pH.

Recommendations for Addressing this Issue

Water systems that use a coagulant should consider whether the elimination of prechlorination and the resulting change in pH would require the system to adjust its coagulant dose or add other chemicals to control pH. Systems with corrosion control should also consider whether a pH change due to the elimination of prechlorination would require the system to alter its corrosion control chemical dose. Impacts of pH changes on compliance and operational issues are described in Section 3.4.

3.3.3 Recommendations for Gathering More Information

Read the Case Study

For more information on simultaneous compliance issues associated with moving the point of chlorination and how to address them, see ***Case Study #1 - Improving and Optimizing Current Operations*** starting on page B-5 of Appendix B. This case study describes how two small PWSs with high THM concentrations were able to comply with the requirements of the Stage 1 D/DBPR and Stage 2 DBPR by adjusting their coagulation methods and changing the point of chlorination, while also optimizing distribution operations to minimize water age and optimizing booster chlorine use.

See Additional References

Readers can turn to Sections 7.1.1, 7.1.2, 7.1.6, and 7.1.17 in Chapter 7 for technical references associated with moving the point of chlorination.

Consider Additional Monitoring

The following are some suggestions for additional monitoring that may benefit water systems moving their point of chlorination:

- ✓ Water systems that reduce or eliminate prechlorination should carefully review pH data to ensure that treatment processes and materials will not be adversely affected;

- ✓ Systems with the potential for iron or manganese problems that move, reduce, or eliminate prechlorination should consider monitoring for those metals at the entry point to the distribution system. Those systems with clearwells and long residence times may want to check whether iron or manganese solids are accumulating in the clearwell;

- ✓ Customer complaint monitoring can be traced along with color and taste and odor evaluations to make sure aesthetic quality has not been lost; and

- ✓ The impact of algal blooms on sedimentation and filter performance can be tracked by measuring turbidity and/or particle counts before and after filtration. Spikes in turbidity or particle counts may indicate a problem with algal blooms.

Consider Other Tools

In addition to water quality monitoring, there are additional tools available in Chapter 6 to help systems evaluate and improve their current water system in relation to the compliance issues they may face when modifying their operation or treatment practices. Examples of tools that can be used when moving the point of chlorination is used as a Stage 2 DBPR compliance technique include:

- The AwwaRF report "Internal Corrosion of Water Distribution Systems" (AwwaRF and DVGW-Technologiezentrum Wasser 1996) which provides bench-scale and pilot testing protocols that can be used to evaluate the impacts of pH changes on corrosion potential. Such pH changes may occur if a utility switches disinfectants;

- The paper "Predicting the Formation of DBPs by the Simulated Distribution System" published by Koch et al. (1991) can be used to predict the amounts of DBPs that would form in a distribution system. Key parameters (including chlorine dosage, incubation temperature, and incubation holding time) are chosen to simulate the conditions of the treatment plant and the distribution; and

- The second version of "Water Treatment Plant Model" (USEPA 2001h) developed by EPA that assists utilities with implementing various treatment changes while maintaining adequate disinfection and meeting the requirements of the Stage 2 DBPR.

Readers are encouraged to read through Chapter 6 before making any final compliance decisions.

3.4 Decreasing pH

Pathogen inactivation by chlorine is affected by pH. This is because the germicidal efficiency of hypochlorous acid (HOCl) is much higher than that of hypochlorite ion (OCl^-), and the distribution of chlorine species between HOCl and OCl^- is determined by pH. Because HOCl dominates at low pH values (< 7.5), chlorination provides more effective disinfection at low pH. At high pH values (> 8.0), OCl^- dominates, which causes a decrease in disinfection efficiency.

Pathogen inactivation by chlorine depends on pH.

Public water systems can reduce their pH to increase disinfectant efficiency, enabling them to lower their disinfectant dose and still achieve the same amount of disinfection, thereby potentially limiting DBP formation. The system may want to raise the pH again before it enters the distribution system to avoid corrosion problems within the distribution system. The ease and desirability of changing pH will depend on the alkalinity and pH of the existing water. Many other treatment processes can also be affected by changing pH, so careful consideration should be given before any change is made.

The pH can also impact reactions between chlorine and NOM, resulting in conditions that favor either TTHMs or HAA5 formation. At higher pH, more THMs tend to be formed. Lower pH tends to favor HAA formation. This information can be used by systems to influence TTHM or HAA5 formation at the plant or in the distribution system by controlling the pH. Systems that have high TTHM levels but relatively low HAA5 may be able to reduce TTHM formation by lowering pH. However, these systems will need to pay special attention to corrosion issues.

3.4.1 Advantages of Decreasing pH

Advantages to decreasing pH include:

- **The same inactivation can be achieved with a lower disinfectant dose or shorter contact time**
- **Can reduce formation of some DBPs**

Same CT Can Be Achieved with Lower Disinfectant Dose

Virus inactivation studies have shown that 50 percent more contact time is required at pH 7.0 than at pH 6.0 to achieve comparable levels of inactivation with chlorine. These studies also demonstrated that an increase in pH from 7.0 to 8.8 or 9.0 requires six times the contact time to achieve the same level of virus inactivation (Culp and Culp 1974).

In general, *Giardia* is the organism that drives the CT required at a water system. Exhibit 3.3 illustrates how pH affects the CT required for 0.5-log inactivation of *Giardia lamblia*. At a pH of 7.0, CT required for free chlorine is 19 mg-min/L. For a pH of 6.5, the CT required is 16 mg-min/L. At a contact time of 16 minutes, this corresponds to a reduction in required free chlorine residual concentration from 1.2 mg/L at a pH of 7.0 to 1.0 mg/L at a pH of 6.5.

Exhibit 3.3 Effects of pH Changes on CT Required for 0.5-Log Inactivation of *Giardia lamblia*

Temperature	pH	CT Required for 0.5 log inactivation of *Giardia lamblia*	Contact time (minutes)	Free Chlorine Residual needed to meet CT Required
10 °C	7.0	19	16	1.2 mg/L
10 °C	6.5	16	16	1.0 mg/L

Source: Adapted from CT tables in 40 CFR 141.74 National Primary Drinking Water regulations.

Can Reduce DBP Formation

The pH of water can impact the formation of halogenated byproducts (Reckhow and Singer 1985, Stevens et al. 1989). Exhibit 3.4 compares formation of byproducts at three pH levels (adapted from Stevens et al., 1989). Note that TTHM show generally lower formation at the lowest pH level. The formation of HAAs, however, generally increases at lower pH levels.

Exhibit 3.4 Impacts of pH on Formation of DBPs

Byproduct	**Conditions of Formation**		
	Chlorination at pH 5.0	**Chlorination at pH 7.0**	**Chlorination at pH 9.4**
TTHM	Lower Formation	Basis for Comparison	Higher Formation
Trichloroacetic Acid (one of the HAA5)	Similar Formation	Similar Formation	Lower Formation
Dichloroacetic Acid (one of the HAA5)	Similar Formation - perhaps slightly higher at pH 7		

Source: adapted from Stevens et al. 1989

Other studies show that limiting pH levels in the distribution system to less than 8.2 may help to limit TTHM formation (Edwards and Reiber 1997). Four LCR compliance strategy case studies showed that TTHM increases were less than 20 percent if the pH shift implemented for lead and/or copper corrosion control was near neutral (7.0) to less than 8.2. When the pH was shifted from near neutral to greater than 8.5, TTHM production increased as much as 40 percent. At one plant, TTHM increases due to pH adjustment ranged from 2 percent at a pH of 8.1 to 43 percent at a pH of 8.7. HAA production was shown to decrease about 10 percent for all of the pH increases implemented (Edwards and Reiber 1997).

3.4.2 Potential Operational and Simultaneous Compliance Issues Associated with Decreasing pH

Potential issues associated with reducing pH to enhance chlorine disinfection include:

- **May increase HAA5 formation;**
- **Can adversely affect treatment plant structures and coatings (i.e., corrosion of pipes, tanks, etc.);**
- **Can affect treatment chemistry, sludge dewatering, and inorganic solubility;**
- **Can cause problems with corrosion control and LCR compliance; and**
- **If chlorine dose is reduced during primary disinfection, it may be difficult to maintain secondary disinfection levels throughout the distribution system.**

HAA5 May Increase

Lower pH conditions may result in higher HAA5 concentrations. Reckhow and Singer (1985) studied humic acid chlorination in laboratory tests and found that trichloracetic acid concentrations reached a maximum when the water was in the acidic pH range. When pH levels were increased, trichloroacetic acid concentrations decreased and chloroform (a key component of TTHM) concentrations increased. Other studies, such as Stevens et al. (1989), have not found comparable increases in HAA5 concentrations when pH levels decreased from neutral to slightly acidic.

<u>Recommendations for Addressing this Issue</u>

In general, pH values in distribution systems are unlikely to fall in the acidic range given the requirements of the Lead and Copper Rule and good corrosion control practices. Systems can conduct simulated distribution system (SDS) studies to simultaneously evaluate impacts of pH adjustment on both TTHM and HAA5 formation. The results of these bench-scale tests can help identify the optimal pH for balancing the need to control both TTHM and HAA5.

Systems can also evaluate pH fluctuation trends throughout their distribution systems. For poorly buffered waters, the pH can tend to drift upward as the water reacts with cement-lined pipes. Increases in pH throughout the distribution system would tend to favor TTHM formation and reduce HAA5 formation.

Adverse Effects on Treatment Plant Materials

If pH levels are lowered to enhance disinfection, components of the treatment plant may be adversely affected by the acidic conditions. Metal components of the plant may corrode; plastic or rubber components may deteriorate more quickly; cement/concrete leaching and deterioration may be exacerbated.

Recommendations for Addressing this Issue

Systems should evaluate the effects of decreased pH on treatment plant components, such as pipes and linings. Based on their evaluation, systems should adjust the:

- maintenance schedules,
- materials, or
- point of pH adjustment

so that the chances of leaks, leaching, or equipment failure are minimized.

Adverse Effects on Treatment Chemistry, Inorganics Solubility, Settling, and Sludge Dewatering

Reducing the water pH can cause problems with increased solubility of inorganics, and may result in increased iron and manganese levels. Lower treated water pH can also result in recalcification of lime-softened waters, resulting in increased turbidity. Variation of pH levels can affect treatment chemistry and impact settling and sludge dewatering. System operators should carefully consider the impacts of pH adjustment before implementing such a significant change to their treatment process.

Manganese is typically removed from water using direct oxidation/coagulation/filtration or filter adsorption/oxidation (i.e., green sand). Chlorine is sometimes used for the oxidation step of this process. A low pH hinders the direct oxidation process because the rate of manganese oxidation increases as pH increases. The oxidation process for manganese is affected at a pH below about 6.2 (USEPA 1999h). Therefore, systems using chlorine or potassium permanganate for manganese oxidation should be aware that, if the pH is reduced before manganese oxidation, more time may be needed for the manganese to be removed. Manganese has also been found to accumulate on filter media of systems that use iron coagulants. This manganese layer can be released if pH and disinfectant conditions change across the filter. Manganese release was found to increase at pH’s as high as 7 and to be rapid at pH 6 (Wert et al. 2005).

The minimum solubility of aluminum occurs at a pH of 6.2 to 6.5. Those water systems that use alum as a coagulant and operate at a pH of less than 6.0 that do not increase their pH before filtration may be impacted by the solubility of aluminum at this low pH. If the pH is not adjusted before filtration, aluminum carryover problems may result.

Recommendations for Addressing this Issue

Systems with high manganese levels that lower the pH prior to filtration may want to consider using an oxidant that is less pH dependent to oxidize manganese, such as ozone. Alternatively, a system could choose to lower the pH after oxidation and filtration. Maintaining a chlorine residual across the filter should prevent manganese from being released in systems using iron coagulants.

Systems using alum as a coagulant can adjust pH to greater than 6.5 before the filters to avoid aluminum passing into the distribution system.

Corrosion Control and LCR Problems

A lower pH in the distribution system can increase corrosion of cement linings and iron pipe. It can also favor corrosion of lead and copper plumbing, causing LCR compliance problems. Corrosion of unlined cast iron water mains can favor microbial regrowth, which can affect TCR compliance.

A drop of one pH unit may cause the desorption of some metal ions, or cause significant dissolution of carbonate or oxyhydroxide mineral scales on lead, copper, iron or other pipe surfaces (Shock 2005).

Any changes in the pH levels historically maintained in a distribution system can disrupt films and scales that have accumulated on natural corrosion surfaces. These films and scales have formed over long periods of time and may be helping to passivate the corrosion process from further development. A decrease of one pH unit may cause the desorption of some metal ions, or cause significant dissolution of carbonate or oxyhydroxide mineral scales on lead, copper, iron or other pipe surfaces (Shock 2005). Although the disruption of films or scales in the distribution system may not result in a direct violation of either the DBP or microbial rules, the disruption could cause aesthetic problems or the release of microbes. Disruption of scale can also cause maintenance problems in utility facilities such as tanks, valves, and pumps, as well as in customer sprinkler systems and commercial facilities.

Recommendations for Addressing this Issue

If pH is lowered during disinfection, systems with pipe materials susceptible to corrosion should consider adjusting pH upward and possibly adjusting alkalinity before the water enters the distribution system to reduce corrosion of pipe materials. If finished water pH is reduced, the system should consider other corrosion control strategies.

Water systems should carefully research the implications of using a corrosion inhibitor before adding it as a treatment step.

Systems can control corrosion by optimizing pH, alkalinity, and dissolved inorganic carbon (DIC). Another alternative is to add a corrosion inhibitor that is phosphate- or silica-based to form a protective coating on pipes. As inhibitor effectiveness is dependent on pipe material and water quality, any system considering using a corrosion inhibitor to offset the effects of lower pH should carefully research the options. Some utilities, however, have elected *not* to use phosphate-based corrosion inhibitors because the publicly owned treatment works (POTW) receiving the wastewater has phosphorus limits in their national pollutant discharge elimination system (NPDES) and sludge disposal permits.

Regardless of the type of corrosion treatment used, it should be tested before it is introduced, if possible. Pilot testing is discussed in more detail in Section 6.3.5 of this manual. Large systems should have completed corrosion control studies, as required by the LCR. Smaller water systems may have conducted studies if required by the state. Any

Appendix D provides additional guidance for systems evaluating their corrosion control options and information on proper piloting procedures.

system that subsequently changes their treatment must notify the state and may be required to conduct a new corrosion control study. In any event, LCR corrosion control studies should be used as a starting point to assess the impacts of changes in distribution system water quality on corrosion and LCR compliance and determine the best corrosion control treatment strategy. Appendix D provides additional guidance for systems evaluating their corrosion control options and information on proper testing procedures.

Reduced Disinfectant Residual Concentration

Systems that are considering lowering their disinfectant dose to take advantage of additional CT credit at a lower pH should consider impacts on maintaining the desired disinfectant residual level throughout the distribution system. A lower disinfectant dose may mean a lower disinfectant residual concentration leaving the treatment plant if the system does not have a chlorine dose point after the clearwells.

Recommendations for Addressing this Issue

Additional chlorine will be needed prior to entry to the distribution system, or through booster disinfection, to account for the decrease in chlorine during primary disinfection.

3.4.3 Recommendations for Gathering More Information

Read the Case Study

For more information on simultaneous compliance issues associated with modifying pH, see ***Case Study #2 Modifying pH During Chlorination*** starting on page B-11 of Appendix B. This case study describes how one PWS used pH depression via carbon dioxide injection ahead of the flocculation basins to reduce DBPs and DBP precursors. The system was also able to increase coagulation efficiency, increase CT throughout the treatment plant (allowing for reduced chlorine injection), and increase and stabilize pH levels in the distribution system by increasing the buffering capacity following caustic soda addition. Their greatest operation issue was a need for a pressurized solution feed to solubilize CO_2.

See Additional References

Sections 7.1.2, 7.1.3, and 7.17 in Chapter 7 contain technical references associated with DBP formation, corrosion, and chlorination, including references on how each process is affected by pH. General water treatment references in Section 7.1.1 can also provide useful information.

Consider Additional Monitoring

The following are some suggestions for additional monitoring that may benefit water systems that are reducing their pH during chlorination:

- ✓ If alum is used as a coagulant and pH is not adjusted back up before filtration, systems should test periodically for aluminum in the finished water;

- ✓ Systems should perform routine pH and alkalinity monitoring at significant locations throughout the treatment plant, especially after corrosion control chemicals have been added;
- ✓ Where it may be a problem, systems should perform periodic monitoring of iron and manganese in the finished water;
- ✓ Systems can perform additional HPC and total coliform monitoring in the distribution system near locations where there is reason to believe that scale may have been dislodged; and
- ✓ Systems can track customer complaints, color, and turbidity in the distribution system if there is reason to believe that changes in pH can affect scales and films.

The purpose of these monitoring suggestions is specifically to address and prevent potential simultaneous compliance issues.

Consider Other Tools

In addition to water quality monitoring, there are additional tools available in Chapter 6 to help systems evaluate and improve their current water system in relation to the compliance issues they may face when modifying their operation or treatment practices. Examples of tools that can be used when modifying pH during chlorination is used for Stage 2 DBPR compliance include:

- The SDS and material-specific (MS-SDS) procedures described by Koch et al (1991) and Brereton and Mavinic (2002), respectively, which describe bench-scale and pilot-scale tests that can be used to evaluate DBP formation under varying chlorine, temperature, and pH conditions;
- The AwwaRF report “Internal Corrosion of Water Distribution System” (AwwaRF and DVGW-Technologiezentrum Wasser 1996) which provides bench-scale and pilot testing protocols that can be used to evaluate changes in corrosion potential due to pH changes;
- The AwwaRF report “Optimizing Corrosion Control in Water Distribution Systems” (Duranceau, et. al 2004) which provides techniques for instantaneous corrosion monitoring;
- The “Guidance Manual for Monitoring Distribution System Water Quality” (Kirmeyer et al. 2002) which can be used to assist water utilities in implementing a distribution system water quality data collection and analysis program; and
- The second version of “Water Treatment Plant Model” (USEPA 2001h) developed by EPA that assists utilities to implement various treatment changes while maintaining adequate disinfection and meeting the requirements of Stage 2 DBPR.

Readers are encouraged to read through Chapter 6 before making any final compliance decisions.

3.5 Reducing Chlorine Dose under Warm Water Conditions

In general, as temperature increases, chlorine reaction kinetics increase. The increased kinetics mean that disinfection effectiveness will improve, but it also means that TTHM and HAA5 will form more quickly. This section discusses the advantages and disadvantages of reducing chlorine residual concentration at the treatment plant during periods of warm water temperature.

3.5.1 Advantages of Reducing Chlorine Dose under Warm Water Conditions

By reducing the chlorine residual at the treatment plant during warm water conditions, systems can achieve:

- **Comparable pathogen inactivation with less chlorine**
- **Reduction in TTHM and HAA5 formation**

Comparable Pathogen Inactivation with Less Chlorine

Systems that use the same chlorine dose throughout the year at their plant to meet CT requirements may be getting significantly higher log inactivation for *Giardia* and viruses in the summer months than in winter months. This is especially true in temperate regions with seasonal changes in source water temperature. Exhibit 3.5 shows how water temperature affects the amount of CT required to achieve 0.5-log *Giardia lamblia* inactivation. Note, for example, how the CT required at 5.0° C and a free chlorine residual of 1.0 mg/L is ***25 mg-min/L***. But when the water temperature increases to 20° C and a free chlorine residual of 1.0 mg/L is used, the CT required for 3-log *Giardia lamblia* inactivation decreases to ***9 mg-min/L***. Systems may be able to provide sufficient CT in the summer months using a lower concentration of free chlorine than the concentration they are using during the winter to provide the same pathogen protection.

Disinfectant residual should not be lowered below the point of compliance with the CT requirements dictated by the SWTR (USEPA 1989). Systems should carefully evaluate their disinfection profiles to ensure that they meet benchmarking requirements and refer to guidance provided in The *Disinfection Profiling and Benchmarking Guidance Manual* (USEPA 1999a).

Systems should ensure that they continue to meet CT requirements

Reduction in TTHM and HAA5 Formation

By reducing the chlorine residual at the treatment plant when water temperatures increase, systems may be able to reduce the formation of TTHM and HAA5. Krasner et al. (1990) found that the median TTHM concentrations in 35 systems were highest for those systems with the highest water temperature.

Exhibit 3.5 Required CT for 0.5-Log Inactivation of *Giardia lamblia* by Free Chlorine at pH 7.0

Free chlorine residual (mg/L)	0.5° C	5.0° C	10.0° C	15.0° C	20° C	25° C
≤ 0.4	33	23	17	12	9	6
0.6	33	24	18	12	9	6
0.8	34	24	18	12	9	6
1.0	35	25	19	13	9	6

Adapted from 40 CFR Part 141 National Primary Drinking Water Regulations § 141.74

3.5.2 Potential Operational and Simultaneous Compliance Issues Associated with Reducing Chlorine Dose under Warm Water Conditions

Some potential issues associated with reducing the chlorine residual concentration at the plant under warm temperature conditions are:

- **Higher disinfectant residual needed for addressing seasonal pathogens (e.g., water is used for recreational purposes, flowing waters with permitted wastewater discharges when flows are low);**

- **Distribution system impacts if finished water chlorine concentration is decreased.**

Seasonal Variability of Pathogen Concentrations in the Source Water

Pathogen concentrations may increase in some surface water sources during the summer months. Concentrations of viruses and enteric bacteria are of particular concern, especially if the source water is also used for recreational activity. Other pathogens such as *Cryptosporidium* have been found to peak during spring runoff.

Recommendations for Addressing this Issue

Systems should evaluate uses of their source water and examine historical data to determine if there is a trend in pathogen occurrence in the warmer months. Systems should also consider consulting with their states to determine if others have collected data for the same source. Many systems will soon have *Cryptosporidium* and/or *E. coli* data available for their source as a result of the LT2ESWTR source water monitoring requirements. If data are not available, systems may want to collect surveillance fecal coliform or *E. coli* samples at their intake to track whether they should be concerned about increased microbial risk.

Distribution System Issues if Chlorine Residual in Finished Water is Decreased

In cases where systems do not add chlorine again after primary disinfection, reducing the chlorine dose at the treatment plant during warmer months may result in lower finished water chlorine residual concentrations. Lower finished water residual levels combined with the faster decay rate of chlorine in the warmer months may make it difficult for some systems to meet the SWTR requirement of maintaining a detectable residual throughout the distribution system.

Distribution systems are also more susceptible to microbial growth during periods of warmer water temperature. Studies have shown that increased water temperatures and corresponding increases in organic matter can enhance coliform re-growth in the distribution system (LeChevallier et al. 1996).

A reduction in chlorine concentration will generally result in a lower oxidation reduction potential (ORP) of the water. ORP is a fundamental characteristic of the water that influences corrosion reactions on metal pipes. In cases where lead oxide (PbO_2) compounds have formed on lead service lines, reductions in ORP can cause dissolution of PbO_2 under certain conditions (Lytle and Schock 2005; Schock and Giani 2004). Reductions in ORP can also cause manganese deposits on pipes to dissolve, potentially depositing again on plumbing fixtures and staining laundry.

Recommendations for Addressing this Issue

If systems are having difficulty maintaining their chlorine residual in the distribution system to meet SWTR requirements, control microbial growth, and ensure compliance with the TCR, they can consider using the distribution system BMPs identified in section 3.2 to reduce disinfectant decay (such as flushing) and to reduce water age (such as improving mixing in storage facilities and installing blowoffs). Booster disinfection may also be a good strategy for maintaining a residual in remote areas of the distribution system.

If reducing the chlorine dose at the treatment plant during periods of warm water temperatures will result in significantly lower chlorine residual in the finished water, systems should consider using various tools and/or monitoring to determine how the change could impact corrosion of metals in the distribution system. Systems could conduct additional monitoring determine the range of ORP levels in the distribution system prior to the change. Appendix D describes various tools that can be used to assess the potential impact of treatment changes on LCR compliance. Systems should also carefully monitor customer complaints to determine if manganese deposits have become a problem.

3.5.3 Recommendations for Gathering More Information

See Additional References

Readers can turn to Sections 7.1.1, 7.1.4, and 7.1.17 in Chapter 7 for general references associated with disinfection, technical references related to distribution system management, and technical references related to chlorination.

Consider Additional Monitoring

The following are some suggestions for additional monitoring that may benefit water systems that are reducing their chlorine dose:

- ✓ Routine raw and finished water monitoring for *E. coli* and total coliform, especially during the periods when the system is reducing its chlorine dose;

- ✓ Increased chlorine residual measurements throughout the distribution system;

- ✓ Increased HPC and total coliform surveillance monitoring in the distribution system;

- ✓ Chlorine demand monitoring prior to chlorine addition for secondary disinfection to make sure stable water is sent into the distribution system; and

- ✓ Inspection of distribution system pipe scales (including service lines and domestic plumbing) to see if reductions in disinfectant residual and/or lower redox potential may cause a problematic change in scale integrity and metal release.

The purpose of these monitoring suggestions is specifically to address and prevent potential simultaneous compliance issues.

Consider Other Tools

In addition to water quality monitoring, there are additional tools available in Chapter 6 to help systems evaluate and improve their current water system in relation to the compliance issues they may face when modifying their operation or treatment practices. Examples of tools that can be used when varying the chlorine dosage is used for Stage 2 DBPR compliance include:

- The *Disinfection Profiling and Benchmarkng Guidance Manual* (USEPA 1999a) describes how systems can develop a disinfection profile and identify their benchmark. It also provides guidance on what constitutes a significant change in disinfection practices.

- The *Guidance Manual for Monitoring Distribution System Water Quality* (Kirmeyer et al. 2002) which can be used to assist water utilities in implementing a distribution system water quality data collection and analysis program;

- The Standard Method 2350 (Oxidant Demand/Requirement) (APHA 1998) that provides step-by-step instructions for the determination of chlorine demand during various water quality conditions; and

- The paper "Predicting the Formation of DBPs by the Simulated Distribution System" (Koch et al. 1991) that can be used to closely monitor and predict changes in DBP formation in the distribution system due to frequent chlorine dose changes.

Readers are encouraged to read through Chapter 6 before making any final compliance decisions.

3.6 Modifying Pre-sedimentation Basin Operations

Pre-sedimentation basins are basins placed before the rapid mix chamber and the flocculation basins. Their purpose is to allow large particles and debris to settle out before the main coagulation process and before any disinfectant is added. Pre-sedimentation basins provide a buffer to turbidity fluctuations and can lower DBP precursors entering the plant. Existing basins can be modified to increase *Cryptosporidium* removal by adding a coagulant or increasing residence time.

3.6.1 Advantages of Modifying Pre-sedimentation Basin Operations

The advantages of pre-sedimentation basins include:

- **Can lower DBP precursors prior to the addition of disinfectants;**
- **Can possibly achieve 0.5 log of *Cryptosporidium* removal credit under the LT2ESWTR; and**
- **Reduce solids loading and improve stability of water quality for downstream treatment processes.**

Lower DBP Precursor Concentrations

By modifying pre-sedimentation basins, systems can remove additional DBP precursors and decrease TTHM and HAA5 formation. Pre-sedimentation basins are especially useful to systems with high levels of solids in their raw water or highly fluctuating turbidity. Addition of a coagulant in the pre-sedimentation basin may increase the removal of DBP precursors.

Addition of a coagulant in the pre-sedimentation basin may increase the removal of DBP precursors.

Cryptosporidium Removal Credit

Systems with pre-sedimentation basins can receive 0.5-log removal credit for *Cryptosporidium*. In order to get the credit for the pre-sedimentation basin, all of the plant's water must pass through the basin and a coagulant must be added whenever the basin is operating. Alternatively, systems can conduct their LT2ESWTR monitoring for *Cryptosporidium* after the pre-sedimentation basin to determine their treatment bin. If a system monitors for bin selection after the pre-sedimentation basin, it cannot get the 0.5 log *Cryptosporidium* removal credit for the basin. These systems may, however, end up in a lower treatment bin due to *Cryptosporidium* removal in the pre-sedimentation basin. See the *LT2ESWTR Microbial Toolbox Guidance Manual* (USEPA N.d.e) for additional information on receiving the removal credit.

Reduce solids loading and improve water stability

Pre-sedimentation basins allow extra time before the water enters the treatment process. This will allow particles suspended by flow to settle out before entering the main treatment train. It will also help to dampen turbidity and particle concentration fluctuations caused by storm events. This will reduce solids loading and fluctuations on downstream processes which can improve process performance.

3.6.2 Potential Operational and Simultaneous Compliance Issues Associated with Modifying Pre-sedimentation Basin Operations

Potential issues associated with using pre-sedimentation basins include:

- **Algal growth in pre-sedimentation basins can increase DBP precursors**
- **Removal of settled solids can be difficult**

Algal Growth

Algae can grow in uncovered pre-sedimentation basins that are not treated with a disinfectant. The algae can add NOM to the water, increasing the chlorine demand, and can negate DBP precursor removal obtained during pre-sedimentation. Algae are also known to produce taste and odor compounds and interfere with flocculation/sedimentation and filtration.

<u>Recommendations for Addressing this Issue</u>

There are several ways to prevent algae growth in pre-sedimentation basins. Potassium permanganate addition has been used with mixed success in efforts to stop algae growth and control resulting tastes and odors. Covering basins to block ultraviolet (UV) light will also prevent algae growth. Although this can be a more expensive solution, floating covers are available that can provide a lower-cost alternative.

Removal of Settled Solids

Solids should be removed on a regular basis to prevent interference with plant performance and compliance with regulatory requirements.

Solids that accumulate in the bottom of pre-sedimentation basins should be removed periodically. This is especially true when a coagulant is added. If a coagulant is not added, systems may be able to manage solids with periodic manual removal. Systems may not be able to use a coagulant if they cannot add solids removal equipment to the basin. Although it presents additional costs to the plant, solids removal should not interfere with plant production if it is done on a regular basis.

<u>Recommendations for Addressing this Issue</u>

If a coagulant is not used, systems should consider using two basins, taking one off-line while the other is being cleaned to avoid stirring up sediment and allowing it to enter the plant.

Solids should be removed on a regular basis to prevent interference with plant performance and compliance with regulatory requirements. Solids can be removed in various ways such as using a sloped floor and center drain or specially designed vacuums or pumps. Removal can be accomplished manually by regular cleaning or dredging.

3.6.3 Recommendations for Gathering More Information

Read the Case Study

For more information on simultaneous compliance issues associated with pre-sedimentation basins and how to address them, see ***Case Study #3 Pre-sedimentation*** starting on page B-19 of Appendix B. This case study describes how one PWS was able to monitor effluent from their pre-sedimentation basins to determine their *Cryptosporidium* bin classification for the LT2ESWTR. Operational issues include problems with algae blooms, which the system was typically able to control by adding potassium permanganate to the basins.

See Additional References

Readers can turn to Section 7.1.1 in Chapter 7 for general technical references associated with water treatment. The final *LT2ESWTR Microbial Toolbox Guidance Manual* (USEPA N.d.e) provides additional information on pre-sedimentation.

Consider Additional Monitoring

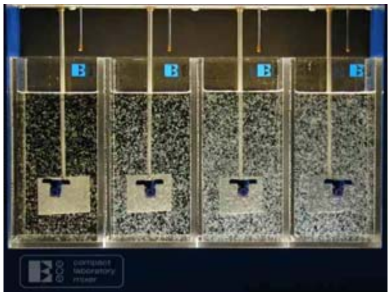
The following are suggestions for additional monitoring that may benefit water systems using pre-sedimentation:

- ✓ Turbidity measurements as water leaves the pre-sedimentation basin and enters the treatment plant, in order to detect impacts of sediment buildup or short-circuiting on water quality entering the plant; and

- ✓ If algae growth is a problem, routine algal counts, chlorophyll *a* measurements, or Secchi disk depth readings as feasible, to guide algae management efforts.

The purpose of these monitoring suggestions is specifically to address and prevent potential simultaneous compliance issues.

3.7 Enhanced Coagulation



One way to remove NOM is to practice enhanced coagulation. Enhanced coagulation has been shown to be an effective strategy for reduction of DBP precursors for many systems (Krasner and Amy 1995). Reduction of pH to between 5 and 6 and/or use of higher coagulant doses has been found effective in reducing TOC to required levels (Krasner and Amy 1995). Enhanced coagulation can include one or more of the following operational changes:

- Increasing coagulant dose
- Changing coagulant
- Adjusting pH (using acid to lower the pH as low as 5.5)
- Improving mixing or applying moderate dosage of an oxidant
- Adding a polymer

As one part of the treatment process is modified, PWSs should consider the impacts on subsequent processes and within the distribution system. Systems considering whether enhanced coagulation may be an effective way to reduce DBPs should refer to the *Guidance Manual for Enhanced Coagulation and Precipitative Softening* (USEPA 1999h).

This section discusses the advantages and disadvantages of enhanced coagulation, and provides recommendations for how systems may be able to address and minimize the disadvantages.

3.7.1 Advantages of Enhanced Coagulation

Some advantages of enhanced coagulation include:

- **May improve disinfection effectiveness**
- **Can reduce DBP formation**
- **Can reduce bromate formation**
- **Can enhance arsenic and radionuclide removal**

Improved Disinfection Effectiveness

All public water systems with a surface water source or a ground water source under the direct influence of surface water must achieve a 3.0 log *Giardia* removal/inactivation and 4.0 log virus removal/inactivation. Enhanced coagulation can improve disinfection effectiveness in three ways:

- Lower the pH during disinfection to improve chlorine effectiveness
- Reduce disinfectant demand
- Remove particles to which pathogens are attached

The pH may be suppressed artificially using an acid or may be the result of heavy alum or ferric coagulant doses.

Chlorine is pH-sensitive, being more effective at low pH values (see Section 3.4 for a more complete discussion of chlorine sensitivity to pH). Therefore, a decrease in pH results in greater inactivation of *Giardia* and viruses. For example, a system with a 1.0 mg/L chlorine residual decreasing its pH from 7.0 to 6.5 at a temperature of 10^{o}C would lower its CT requirement for 3 log Giardia inactivation from 112 mg-min/L to 94 mg-min/L. Ozone also exhibits increased performance at lower pH values (Carlson et al. 2000). Conversely, chlorine dioxide can be less effective at low pH values and less monochloramine is formed at lower pH.

The removal of NOM through enhanced coagulation may allow increased disinfectant efficiency by decreasing the demand on the disinfectants exerted by organics (Carlson et al. 2000). The amount of NOM removed will vary depending on the pH, coagulant, coagulant dose, and NOM properties. The amount of NOM removal for a given system can be determined using jar tests. Alternatively, computer models are available that can predict organic removal given the pH, coagulant dose, and organic properties (Edwards 1997). For a system to realize this benefit, the system should inject the disinfectant at a location in the treatment process where NOM removal has been achieved. This operational scenario may allow the system, in consultation with its regulatory agency, to reduce the amount of disinfectant used compared to dosages required prior to practicing enhanced coagulation. A reduction in the amount of disinfectant applied should result in fewer DBPs being formed. The system should, however, ensure that the necessary microbial inactivation is maintained at all times by measuring:

- The disinfectant residual
- Flow, temperature, and pH
- Calculating the resulting inactivation contact times and CTs being achieved

Increased removal of organic particles obtained using enhanced coagulation can have the added benefit of removing additional microbial pathogens. For example, States et al. (2002) found that enhanced coagulation with filtration could achieve 5.0 log removal of *Cryptosporidium* compared to an estimated 2.0 log removal by filtration without coagulation.

Reduced DBP Formation

Enhanced coagulation improves the removal of DBP precursors in a conventional water treatment plant. The removal of TOC (a surrogate measure of NOM) by coagulation has been demonstrated in several laboratory research, pilot demonstrations, and full-scale studies (Chowdhury et al. 1997, Edwards 1997). Removal of TOC can result in a decrease in TTHM and HAA5 formation. In fact, the Stage 1 D/DBPR uses TOC to define enhanced coagulation for DBP precursor removal regulatory requirements. The actual reduction in TOC can vary widely. Systems can obtain a better idea of the removal they can obtain by using jar tests.

Reduced pH, which is usually characteristic of enhanced coagulation, has also been demonstrated to result in a reduction in formation of chloroform (Singer 1999). A more detailed discussion of this topic is provided in Section 3.4.

Reduced Bromate Formation

The reduction of pH that is commonly practiced as part of enhanced coagulation can result in better control of bromate formation for those systems using ozone. Williams et al. (2003) indicated that a pH of about 6.5 provided effective reduction of bromate formation. The effectiveness of bromate control at lower pH values depends on the source water, particularly its alkalinity.

Arsenic and Radionuclide Removal

Compliance with the new arsenic maximum contaminant level (MCL) of 0.010 mg/L may require systems to consider treatment modifications for improved arsenic removal. Some systems may realize improved arsenic removal by using a ferric coagulant as part of the enhanced coagulation process. Scott et al (1995) observed that arsenate (As(V)) removal was in the range of 80 to 95 percent for a ferric coagulant dose ranging from 3 to 10 mg/L. Alum coagulation has been shown to remove arsenic, but at higher doses (up to 20 mg/L) Removal of arsenite (As(III)) is much less efficient than As(V), though iron coagulants are still more effective at removing As(III) than alum coagulants (Hering et al. 1996; Edwards 1997). Modified coagulation is identified by EPA as a Best Available Technology (BAT) for the Arsenic Rule.

Enhanced coagulation may also provide better radionuclide removal since radionuclides, such as uranium, have been shown to be removed by coagulation/filtration (Sorg 1988). Systems will want to understand fully their requirements for disposal of residuals containing radionuclides and check with their State or Primacy Agency for instructions on special handling or disposal of residuals containing radionuclides.

3.7.2 Potential Operational and Simultaneous Compliance Issues Associated with Enhanced Coagulation

Potential issues associated with enhanced coagulation include:

- **Adverse impacts to filtration process**
- **Corrosion concerns**
- **Increased concentrations of inorganics in the finished water**

- **Additional issues with residual disposal**

This section discusses these issues briefly and provides suggestions for reducing their impacts.

Adverse Impacts to Filtration Process

In most cases, lowering the pH and/or increasing coagulant feed will result in lowering turbidity in the finished water. However, lower pH levels can sometimes lead to the formation of a less dense, more fragile floc. This type of floc can carry over from the clarifier and may result in shorter filter run times or premature filter breakthrough (Singer 1999). A lower pH and higher coagulant dose may also result in restabilization of particles. These conditions can create upsets in solids blanket-type clarifiers (Carlson et al. 2000).

Premature filter breakthrough as a result of higher particle loading to the filter could result in shorter filter runs or, if a system does not adjust its operations in response to the higher particle loading, the system might not meet the turbidity limits established by the IESWTR and LT1ESWTR. This may also trigger individual filter follow-up actions as required by IESWTR and LT1ESWTR. Conversely, enhanced coagulation may have a positive effect on subsequent treatment steps, resulting in lower finished water turbidity, potentially longer filter runs, and better compliance with effluent turbidity limits.

<u>Recommendations for Addressing this Issue</u>

Systems may want to pilot test different coagulants to identify the coagulant type and dose that produces the most stable, settleable floc. Lovins et al. (2003) found that ferric sulfate produced a larger, more durable and more settleable floc relative to alum in Peace River water, a high DOC water, at a pH of around 7.5.

Systems should consult the *Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual* (USEPA 1999h) for recommendations on how to maintain low turbidity while performing enhanced coagulation.

Corrosion Concerns

Corrosion control within the distribution system and water treatment plant can be affected by a change in pH, change in the chloride to sulfate ratio, change in organics concentration, or a significant change in the alkalinity of the finished water (Carlson et al. 2000). Any of these conditions can occur as a result of enhanced coagulation and can potentially create compliance issues with the LCR or result in degradation of plant facilities.

Enhanced coagulation lowers TOC. Changes in TOC have been found to have differing impacts on corrosion. Schock et al. (1996) found that in some cases, NOM can form soluble complexes with lead which can increase corrosion. In other cases, NOM was found to coat the pipes and lower corrosion rates. Edwards et al. (1996) have reported similar results for copper corrosion. Edwards et al. (2004) found that lower TOC in combination with higher aluminum may cause pinholes leaks in copper piping.

Enhanced coagulation can lower alkalinity. The effect of an alkalinity change depends on the initial alkalinity; for water with moderate to low alkalinity, a decrease in alkalinity can increase corrosion. Lower alkalinity can also damage concrete in pipes or in basins and reservoirs. Systems are encouraged to maintain a minimum alkalinity of 10 to 20 mg/L as calcium carbonate. If the initial alkalinity is high, however, a decrease may be beneficial since a decrease in alkalinity can also decrease copper corrosion rates.

Enhanced coagulation lowers pH. Lower pH generally increases corrosion rates. Changing distribution system pH can also alter the condition of pre-existing scale. The lower the initial pH, the smaller the pH change needed to affect the corrosion rate. At an initial pH of 7, a pH change of 0.2 can affect corrosion, while with an initial pH of 9 it takes a pH change of over 0.5 to significantly affect corrosion (AWWA 2005a). Softened scale can break off and release any material contained in the scale into the distribution system water.

Lower pH can also have adverse impacts within the treatment plant. Cement can degrade in acidic conditions. Metals in pipes and pumps may also be susceptible to corrosion.

If aluminum coagulants are used and filtration is not optimized, efforts to perform enhanced coagulation may result in increased aluminum concentrations. Aluminum can increase corrosion of lead and copper, though it will decrease corrosion of copper byproducts.

The increased use of coagulants in enhanced coagulation will raise the concentration of the anion, either sulfate or chloride, and will affect the chloride to sulfate ration. A low chloride to sulfate ratio has been shown to decrease corrosion rates (Edwards et al.1999).

Recommendations for Addressing this Issue

Systems should consider adjusting their pH upward before the water enters the distribution system in order to reduce corrosion of pipe materials. Systems will want to identify the optimum pH within the distribution system that enables compliance with the LCR and does not result in substantial increases in DBP levels.

Water systems should carefully research the implications of using a corrosion inhibitor before adding it as a treatment step.

There are several options available to increase pH. These include addition of lime, caustic soda, soda ash, and sodium bicarbonate. Another possible method of increasing pH is to filter using limestone or other alkaline media. Each of these techniques has advantages and disadvantages that will depend on the water quality of the water being adjusted and the distribution system materials that must be protected. For example, soda ash raises alkalinity as well as pH. The increased alkalinity can cause increased corrosion of some materials (Kirmeyer et al. 2002). The reference tools listed at the end of this section provide more guidance on proper selection of pH adjustment techniques.

If the system cannot readjust the pH to a high enough level using caustic to prevent corrosion, it can consider adding a corrosion inhibitor (i.e., a substance that is phosphate- or silica-based) to the finished water to form a protective coating on the pipes.

Water systems should carefully research the implications of using a corrosion inhibitor before adding it as a treatment step. Some utilities have elected not to use phosphate-based corrosion inhibitors because the POTW receiving the wastewater violated phosphorus limits in their disposal permits. Zinc toxicity to wastewater treatment biota can also be a concern. Lime addition can potentially cause turbidity problems if the dosing and mixing are not done properly. Conversely, research has shown that corrosion control often has the added benefit of controlling biological growth in the distribution system, which can lead to improved compliance with the TCR.

Regardless of the type of corrosion inhibitor used, it should be carefully pilot-tested before it is introduced. Large water systems were required to conduct corrosion control studies under the LCR. Smaller systems may have conducted studies if required by the state. Any system that subsequently changes their treatment must notify the state and may be required to conduct a new corrosion control study. In any event, LCR corrosion control studies should be used as a starting point to assess the impacts of changes in distribution system water quality on corrosion and LCR compliance and determine the best corrosion control treatment strategy. Appendices C and D provide additional guidelines for systems evaluating their corrosion control options and information on proper piloting procedures.

Systems should also monitor inside the plant for signs of corrosion of concrete or metal. If corrosion is noticed, corrosion may be prevented by applying an epoxy coating. For metals such as pipes and pumps or metal rebar in concrete structures, using a sacrificial anode is an option in addition to epoxy coatings. Exterior fittings in buildings should be painted to reduce corrosion. Finally, materials compatible with the anticipated pH and water quality in the plant should be specified when designing new processes.

Increased Inorganics in Finished Water

Enhanced coagulation can cause an increase in inorganics, such as manganese, aluminum, sulfate, chloride, and sodium in the finished water. The low pH that frequently results from enhanced coagulation reduces the oxidation rate of manganese from the dissolved state (Mn^{2+}) to the solid form (MnO_2) that allows it to be removed during sedimentation and filtration. Ideally, manganese is completely oxidized before the coagulation step, and enhanced coagulation should not deter manganese removal. Systems should note, however, that even very low concentrations of manganese (e.g., 0.05 mg/L) in the finished water could result in aesthetic problems.

Manganese may also be present in concentrations above the secondary standard of 0.05 mg/L if high dosages of ferric coagulants are used (Carlson et al. 2000). Ferric chloride and ferric sulfate coagulants can contain relatively high concentrations of manganese. If a water system switches from low doses of ferric or alum to high doses of ferric, the coagulant itself may significantly increase the amount of dissolved manganese in the water.

The presence of high concentrations of sulfate or chloride may affect the corrosivity of the water (Carlson et al. 2000). The mass ratio of chloride to sulfate can also affect the corrosivity of the water. Edwards et al. (1999) found that of 24 utilities surveyed, none of the utilities with a chloride to sulfate ratio of less than 0.58 exceeded the lead action level, while 64 percent of utilities with a ratio greater than 0.58 exceeded the lead action level.

Increased aluminum in the distribution system may result when high alum dosages are used in an effort to perform enhanced coagulation. Increased aluminum can lead to aesthetic problems, such as solids precipitation, in the distribution system (Carlson et al. 2000). Increased alum can be kept from passing through filters by addition of filter aids and more frequent backwashing. More frequent backwashing, however, has costs and other implications.

<u>Recommendations for Addressing this Issue</u>

System operators should consider their source water specifically when making choices about coagulant use. Systems should jar test and, ideally, pilot test under different water quality conditions the coagulants that they are considering before making full-scale coagulant treatment changes. NSF and manufacturer recommendations should be followed in coagulant dosing. Specifications for coagulants and other treatment chemicals should also specify allowable concentrations of trace contaminants. Section 6.3 describes some ways systems can test their water to determine which coagulant is best suited for their water quality and particular treatment needs. Systems with a high chloride to sulfate ratio may be able to mitigate corrosion by switching from a chloride-based coagulant to a sulfate-based coagulant.

Residuals Handling

Because more coagulant is added and more organics are being removed, enhanced coagulation will likely result in the production of more waste residuals. The conditions for existing disposal of water treatment plant (WTP) sludge should be reviewed and even renegotiated, and increased costs of waste disposal should be factored into a system's decision.

If the source water has high concentrations of hazardous contaminants such as arsenic, the waste residuals may concentrate these contaminants to the extent that the waste is considered unfit for disposal in a sanitary landfill. Some states have stricter limits on toxics concentrations in waste residuals disposed of in sanitary landfills, and exceeding any of those limits could cause the waste to be classified as hazardous. In addition, some states have additional disposal requirements for residuals that have been characterized as technologically enhanced naturally occurring radioactive material (TENORM) that can further complicate disposal.

<u>Recommendations for Addressing this Issue</u>

Systems will likely experience higher costs with managing an increased residual load. Depending on how residuals are managed, additional facilities may need to be constructed or new permits may be necessary. Aluminum is toxic to aquatic life, so increased alum use may result in limitations on the discharge of the residual stream to surface water bodies.

Systems should properly analyze the sludge that results from enhanced coagulation for increased metals and other contaminants that may create issues with final sludge disposal. The regulatory agency should be consulted regarding disposal of residuals if hazardous chemicals are concentrated in the residuals. EPA has recently released *A Regulator's Guide to the Management of Radioactive Residuals from Drinking Water Treatment Technologies*, (USEPA 2005c) which deals with the issue of radioactive compounds concentrated in residuals.

Typically, ferric sulfate sludges are more easily dewatered as compared to alum sludges (Thompson and Paulson 1998).

3.7.3 Recommendations for Gathering More Information

Read the Case Studies

Four case studies in Appendix B describe simultaneous compliance challenges faced by utilities using enhanced coagulation.

Case Study #1 - Improving and Optimizing Current Operations starting on page B-5 of Appendix B describes how two small PWSs with high THM concentrations were able to comply with the requirements of the Stage 1 D/DBPR and Stage 2 DBPR by adjusting their coagulation methods and changing the point of chlorination, while also optimizing distribution operations to minimize water age and optimizing booster chlorine use. Their greatest operation issue was a need for increased attention to solids removal as a result of enhanced coagulation

Case Study #4 Switching Coagulants starting on page B-23 describes how a system could simultaneously comply with the TOC removal requirements of the Stage 1 D/DBPR and the turbidity removal requirements of the IESWTR by switching coagulants. The system found that enhanced coagulation with ferric sulfate not only increased TOC removal significantly, but also reduced turbidity levels in the finished water. The major problem experienced in implementing the treatment modification was the control of manganese and corrosion in the rapid mix chamber due to the addition of sulfuric acid.

Case Study #5 Enhanced Coagulation-Problems with Copper Pitting starting on page B-29 describes a system that experienced pinhole leaks in their copper piping following alterations to the coagulation process. The system implemented orthophosphate addition to address the pinhole leaks, which also had an effect on finished water turbidity and iron release from unlined cast iron mains.

Case Study #6 Enhanced Coagulation - Managing Radioactive Residuals starting on page B-33 provides a discussion of a system's options for disposing of radioactive residuals resulting from enhanced coagulation. As a result of enhanced coagulation, radionuclides can become concentrated in residuals at levels that require special consideration for regulatory approval of sludge disposal.

See Additional References

Readers can turn to Section 7.1.8 in Chapter 7 for technical references associated with using enhanced coagulation.

Consider Additional Monitoring

The following are some suggestions for additional monitoring that may benefit water systems using enhanced coagulation:

- ✓ Routine turbidity or particle count monitoring of water leaving the sedimentation basin to ensure that a consistently stable and dense floc is forming;
- ✓ Routine finished water pH and alkalinity monitoring to help ensure that corrosion control is being implemented correctly; and
- ✓ Periodic aluminum measurements in the finished water to watch for aluminum carryover from the combination of alum floc and low pH.

The purpose of these monitoring suggestions is specifically to address and prevent potential simultaneous compliance issues.

Consider Other Tools

In addition to water quality monitoring, there are additional tools available in Chapter 6 to help systems evaluate and improve their current water system in relation to the compliance issues they may face when modifying their operation or treatment practices. Examples of tools that can be used when enhanced coagulation is used for Stage 2 DBPR compliance include:

- The "Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual" (USEPA 1999h) that provides recommended procedures for conducting jar testing to determine the optimum coagulation conditions for achieving desirable total organic carbon removal and coagulated/settled water turbidity;
- The AwwaRF report "Internal Corrosion of Water Distribution System" (AwwaRF and DVGW-Technologiezentrum Wasser 1996), which provides bench-scale and pilot testing protocols that can be used to evaluate changes in corrosion potential due to changes in pH;
- EPA's Environmental Technology Verification Program collects performance data on many environmental technologies, including enhanced coagulation. Reports for each technology can be found on the website at: http://www.epa.gov/etv/verifications/verification-index.html;
- The "Guidance Manual for Monitoring Distribution System Water Quality" (Kirmeyer et al. 2002) which can be used to assist water utilities in implementing a distribution system water quality data collection and analysis program;
- The second version of "Water Treatment Plant Model" (USEPA 2001h) developed by EPA that assists utilities with implementing various treatment changes while maintaining adequate disinfection and meeting the requirements of Stage 2 DBPR; and
- The Partnership for Safe Water publishes many materials useful in optimizing filter performance. More information can be found on their website at: http://www.awwa.org/science/partnership/.

Readers are encouraged to read through Chapter 6 before making any final compliance decisions.

3.8 Enhanced Softening

Precipitative softening with lime addition is typically practiced with the objective of removing hardness in the form of calcium and magnesium from water. Total hardness removal goals vary among treatment plants. Lime softening processes are generally divided into three distinct groups:

- Conventional lime softening to remove calcium carbonate where only lime is fed;
- Lime-soda softening to remove calcium carbonate and noncarbonate hardness by feeding both lime and either soda ash or potassium carbonate; and
- Excess lime softening to remove both calcium and magnesium (and sometimes silica) by adding an excess of lime.

All softening plants operate at higher pH levels than conventional coagulation plants. Calcium carbonate begins to precipitate above pH of 9.5 and as the pH increases above 10, magnesium hydroxide precipitation increases.

Generally, removal of TOC in softening is enhanced by the addition of a small amount of coagulant.

Softening has some similarities to coagulation with respect to the mechanisms operating to remove particles and TOC, so that when coupled with appropriate settling, DBP precursors can be removed effectively by softening. Generally, removal of TOC in softening is enhanced by the addition of a small amount of coagulant. The regulatory requirement for enhanced softening in the Stage 1 D/DBPR is based on the assumption that raising the lime dose will foster the precipitation of $CaCO_3$ and the associated coprecipitation of precursors. The resulting increase in pH causes increased precursor removal, presumably by promoting stronger interactions between the precursors and calcium ions. In addition, the increase in pH may be sufficient to precipitate magnesium hydroxide, which strongly adsorbs precursors (Randtke 1999; Shorney and Randtke 1994).

When the pH of softening is changed significantly, differences in process chemistry affect the nature of the solids that are formed with respect to settling and dewatering characteristics. Enhanced softening criteria do not require plants to alter the softening process to the extent that major changes in settling conditions and solids handling are generally required. A plant is considered to be practicing enhanced softening if it meets the appropriate TOC removal target in the 3x3 TOC removal matrix. Most softening plants have raw water alkalinity above 120 mg/L as $CaCO_3$, so that they are classified in the right hand column of the matrix, but a few fall into the classification for influent with alkalinity of 60 – 120 mg/L. Plants that cannot meet the removal requirements in the 3x3 matrix may remain in compliance by removing a minimum of 10 mg/L of magnesium as $CaCO_3$. Alternatively, softening plants that reduce their finished water alkalinity to 60 mg/L are in compliance with enhanced softening.

3.8.1 Advantages of Enhanced Softening

The main advantages of enhanced softening are:

- **Adequate removal of TOC**
- **Two stage plants may achieve additional *Cryptosporidium* removal credit**
- **Lower corrosion impacts**

Adequate Removal of TOC

Softening plants typically do not have difficulty meeting the TOC removal requirements of the 3x3 matrix in the Stage 1 D/DBPR. Information from a survey of softening plants (Clark et al. 2000) indicated that operational data showed TOC being removed at least at the level defined by the matrix, and this is substantiated by the data from the Information Collection Rule (ICR). Since plants were not necessarily striving to meet the enhanced softening criteria during the ICR sampling period, apparently the standard operating scheme for most softening plants actually falls within the criteria of “enhanced softening” as defined by the rule (Clark et al. 2000).

The only instances reported by softeners which lead to difficulty in removing TOC occur when raw water alkalinity drops significantly causing the calcium hardness:carbonate alkalinity ratio to be elevated. This situation can arise when surface water is diluted by major rain events or when a blend of ground and surface water is altered in proportions. In these cases, some addition of carbonate alkalinity in the form of soda ash or potassium carbonate may be warranted to facilitate the softening reactions and the coprecipitation of organic material. Softening utilities are expected to be able to meet the requirements of the Stage 2 DBPR as effectively, or more so, as conventional coagulation plants (USEPA N.d.e).

Two Stage Plants May Achieve Additional Cryptosporidium Removal Credit

Plants that include a two-stage lime softening process are eligible for an additional 0.5-log *Cryptosporidium* removal credit toward compliance under LT2ESWTR if chemical addition and hardness precipitation occur in two separate and sequential softening stages prior to filtration. The two-stage process must consist of a second clarification step between the primary clarifier and filters. Both clarifiers must treat all of the plant flow. Refer to the *LT2ESWTR Toolbox Guidance Manual* (USEPA N.d.e) for a description of the requirements for receiving this credit.

Lower Corrosion Impacts

Softening systems have an advantage with respect to managing corrosion for two reasons. Since the softening process takes place at a pH above 10, systems generally add carbon dioxide to reduce pH and stabilize the water prior to distribution. Selection of an appropriate finished water pH goal takes into consideration the optimum pH for corrosion control. At the same time, softening systems generally produce water that tends to develop scale in the distribution system.

If the scale formation is not managed appropriately, it can be a liability with respect to flow restriction, but from a corrosion control standpoint, scale formation is a distinct benefit.

As noted in EPA's "Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual" (USEPA 1999h), the information in Exhibit 3.6 is intended only to characterize existing and future corrosion control strategies. The figure can be used proactively to anticipate problems that may develop if enhanced softening is used.

Exhibit 3.6 Effect of the Change of Water Quality Parameters Due to Enhanced Softening on Corrosion of Piping System Materials

Parameter	Potential Change Resulting From Enhanced Softening		Impact on Corrosion of Material									
			Pb		Cu		Fe		Pb from Brass		Concrete	
TOC	▼		▶		▶[1]	▼[2]	▼		▼	▶	▲	
Alkalinity	▼	▶	▶		▶		▲	▶	▼	▶	▲	▶
Ca Hardness	▼		▶		▶		▲	▶	▶		▲	
pH	▲	▶	▼	▶	▼	▶	▼	▶	▼	▶	▶	
[1] applies to copper [2] applies to copper by-products			▼ = decrease				▲ = increase				▶ = same (no change)	

Source: USEPA's Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual (USEPA 1999h)

3.8.2 Potential Operational and Simultaneous Compliance Issues Associated with Enhanced Softening

Potential issues associated with enhanced softening include:

- **Options for disinfection are limited**
- **Higher TTHM formation at high pH**
- **Can cause scaling**
- **pH adjustment required for distribution and for disinfection effectiveness**
- **Increased sludge volume and changes in sludge characteristics**

This section briefly describes these issues and provides suggestions for minimizing their impacts.

Disinfection considerations

One of the most complex issues facing softening plants with respect to regulatory compliance is selection and implementation of disinfection processes. Disinfection with chlorine, chloramines, chlorine dioxide, and ozone requires specific consideration of issues that arise in high pH waters.

Based on data from an AWWA survey of softening plants completed in 1997 to inform the regulatory development process, more than one third of softening plants predisinfect with chlorine, ozone, or a combination of chlorine/chloramines and they take CT credit for some or all predisinfection contact time. In addition, the survey indicated that the finished water pH in softening plants ranges from 7.5 to 10, with approximately half reporting average finished water pH greater than 9. CT values for inactivation of *Giardia* by free chlorine and chloramines are not identified for pH levels greater than 9 in the SWTR Guidance (USEPA 1991). Thus, the state must evaluate disinfection credit using chlorine or chloramines through the softening portion of the treatment process on a case-by-case basis to ensure that the total treatment processes achieve at least 3-log treatment of *Giardia* and 4-log treatment of viruses. Some softening plants have resolved this problem by providing appropriate contact time after softening and pH reduction to meet required CT values with their selected disinfectant.

The state must evaluate disinfection credit using chlorine or chloramines through the softening portion of the treatment process on a case-by-case basis.

Use of chlorine dioxide in softening plants is governed by the regulated levels for chlorine dioxide and chlorite. Chlorine dioxide reacts with many organic and inorganic constituents in water. It disinfects by oxidation, but does not chlorinate. Chlorine dioxide functions as a highly selective oxidant due to its unique, one-electron transfer mechanism where it is reduced to chlorite. The reactions produce chlorite and chlorate as endpoints. In drinking water, chlorite (ClO_2^-) is the predominant reaction endpoint, with approximately 50 to 70 percent of the chlorine dioxide converted to chlorite and 30 percent to chlorate (ClO_3^-) and chloride (Cl^-) (USEPA 1999h). The balance between these two species varies frequently and is affected by the exposure to bright sunlight, aeration, and recarbonation, among other factors (Gates 1997). The disproportionation of ClO_2 is accelerated by increased pH, which means that the addition of lime soon after the addition of ClO_2 may result in minimal disinfection time and development of both chlorite and chlorate (Hoehn 1993). There may be situations in which chlorine dioxide can be used as a preoxidant in softening plants, but they would be governed by the contact time available prior to the addition of lime and initiation of the softening process.

Ozone use at high pH (above pH 7) will form significant bromate when bromide is present in the water. Ozonation at lower pH can control the formation of bromate, but will increase the formation of brominated organic byproducts produced from the interaction between hypobromous acid and NOM, producing an overall increase in TTHM by weight (Reckhow 1999). In softening plants, the use of ozone generally requires reduction of pH from the softening pH (between 10 and 11) to a pH between 6 and 7. To obtain such a shift in pH, significant amounts of acid are often consumed. Thus, unless a unique water quality concern requires use of ozone, other disinfection options should be considered.

Higher THM Formation

In addition to increasing with chlorine dose and presence of DBP precursors, THM formation has been shown to be higher with increasing chlorination pH. Some HAAs, in contrast appear to have lower formation at higher pH (Singer 1999). A number of softening plants have constructed a large chlorine contact chamber/clearwell to provide disinfection contact time after the pH of the water is lowered from the softening pH to a pH that minimizes DBP production.

Many raw water sources that are treated by softening contain significant levels of bromide. As plants practice enhanced softening to remove precursors, the ratio of the amount of bromide in the water to the amount of TOC goes up because bromide is not removed by softening. Research has shown that as the ratio of bromide to TOC increases the percentage of brominated DBPs increases. Thus, when bromide-containing enhanced softened water is disinfected with chlorine, formation of brominated THMs increases, resulting in a higher total weight of THMs formed. Thus, softening plants may be forced into a balancing of TOC removal with DBP formation to optimize the finished water DBP formation based on speciation of the THMs and total weight of TTHM.

Recommendations for Addressing this Issue

If softening plants have problems complying with the proposed Stage 2 DBPR TTHM MCLs, three possible alternatives should be considered.

- Systems may be able to reduce finished water pH somewhat to reduce the TTHM formation potential in the system. Changes in system pH should be cautiously undertaken to ensure that the existing system scale is not altered significantly, softened, or stripped from pipes, thereby causing major operational problems;

- Systems may be able to utilize alternative disinfectants, including chloramines, chlorine dioxide, or ozone. Chloramines are best suited for use as a distribution system residual although some softening plants operate with a chloramine residual carried through the softening process. Chlorine dioxide and ozone disinfection should be evaluated with care in both quantity and placement to ensure that neither chlorate nor bromate MCLs are violated. Use of UV for disinfection may reduce the level of chlorine or chloramine residual required for residual disinfection in the distribution system; and

- Softening plants may also evaluate the possible conversion from conventional softening to membrane softening. The use of microfiltration followed by nanofiltration can remove TOC as well as provide softened water, thereby reducing the DBP formation potential. Cost may be a factor that prohibits a system from making this change. In addition, membrane conversion can necessitate the need to consider other simultaneous compliance issues such as ensuring that distribution system chemical equilibrium is not altered in a way that will cause either corrosion or scale sloughing.

Scaling

Depending on the raw water quality and the physical configuration of the treatment processes in a softening plant, the addition of extra lime to provide enhanced softening conditions can lead to increased scaling conditions in both the treatment plant and the distribution system piping. In general, if the Langelier Saturation Index (LSI) is positive, the water is oversaturated with $CaCO_3$ and has the potential to precipitate and form scale.

pH Adjustment Required for Distribution and for Disinfection Effectiveness

Most softening plants adjust pH to meet finished water pH goals, to meet pH requirements for disinfection effectiveness after the completion of the softening process, and to satisfy distribution system chemical equilibrium. As the pH of softening is increased in an effort to remove more TOC, the quantity of chemical required for pH adjustment increases. Historically, the finished water pH in softening plants has ranged between 7.5 and 10.

Increased Sludge Volume and Changes in Sludge Characteristics

Significant increases in lime doses will result in increased lime sludge production. Residuals production may also increase when lime addition results in a pH greater than 10.25 in plants with significant magnesium present that have not historically softened at pH greater than 10. At that pH, the magnesium hydroxide is precipitated along with calcium carbonate. If significant noncarbonate hardness exists, then addition of soda ash may be necessary, resulting in increased residuals production and higher sodium levels in the finished water. In addition, the handling and dewatering characteristics may be significantly altered (Randtke et al. 1999).

In the softening process, calcium carbonate forms a dense crystal that is negatively charged, while magnesium hydroxide forms large, light floc that has a high surface area and positive surface charge. This difference in particle characteristics is what makes magnesium hydroxide a better adsorbent for dissolved precursors; however magnesium hydroxide solids have settling and dewatering characteristics that are quite different from calcium carbonate solids. In fact, softening plants that are designed to settle calcium carbonate may very well have inadequate settling time to settle magnesium hydroxide. If the previous softening pH was less than 10.25 and the water has significant magnesium, then enhanced softening in which the pH is increased to greater than 10.25 can cause formation of magnesium hydroxide, which may not be effectively removed in the settling process, or may change the characteristics of the process solids.

3.8.3 Recommendations for Gathering More Information

See Additional References

Readers can turn to Section 7.1.8 of Chapter 7 for technical references associated with enhanced softening

Consider Additional Monitoring

The following are some suggestions for additional monitoring that may benefit softening systems. The purpose of these monitoring suggestions is specifically to address and prevent potential simultaneous compliance issues.

- ✓ Routine LSI measurements, or another comparable calcium carbonate saturation index, of water entering the distribution system to monitor the potential for excess scale formation. Weekly measurements may be sufficient when raw water quality is relatively consistent. More frequent checks may be useful under changing raw water conditions.

Consider Other Tools

In addition to water quality monitoring, there are additional tools available in Chapter 6 to help systems evaluate and improve their current water system in relation to the compliance issues they may face when modifying their operation or treatment practices. Examples of tools that can be used when enhanced softening is used for Stage 2 DBPR compliance include:

- The “Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual” (USEPA 1999h) that provides recommended procedures for conducting jar testing to determine the optimum coagulation and softening conditions for achieving desirable total organic carbon removal and coagulated/settled water turbidity;

- The AwwaRF report “Internal Corrosion of Water Distribution System” (AwwaRF and DVGW-Technologiezentrum Wasser 1996) which provides bench-scale and pilot testing protocols that can be used to evaluate changes in corrosion potential due to changes in pH;

- The “Guidance Manual for Monitoring Distribution System Water Quality” (Kirmeyer et al. 2002) which can be used to assist water utilities in implementing a distribution system water quality data collection and analysis program; and

- The second version of “Water Treatment Plant Model” (USEPA 2001h) developed by EPA that assists utilities with implementing various treatment changes while maintaining adequate disinfection and meeting the requirements of Stage 2 DBPR.

Readers are encouraged to read through Chapter 6 before making any final compliance decisions.

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4 Installing New Total Organic Carbon or Microbial Removal Technologies

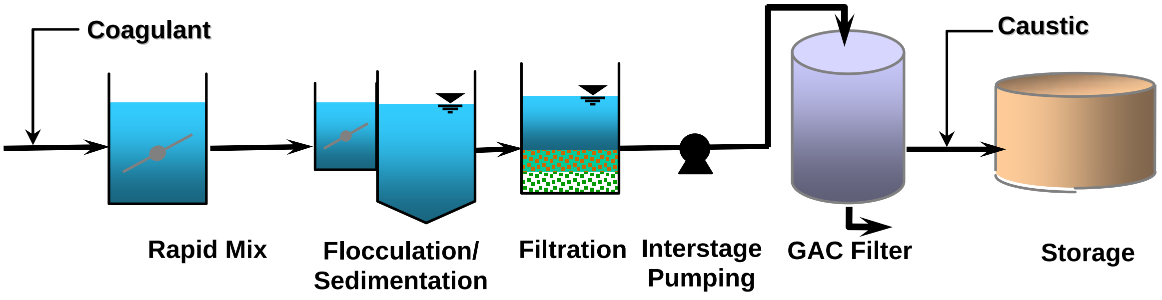
After improving and optimizing current operations, some water systems will still need to install a new type of treatment in order to comply with the Stage 2 DBPR and/or the LT2ESWTR. This chapter describes treatment technologies that can be installed to remove DBP precursors and microbial pathogens. Advantages of using each treatment are described, along with summaries of operational and simultaneous compliance issues associated with the treatment. General recommendations for addressing those issues are provided, along with recommendations for gathering more information. While most of the issues presented in the following sections address simultaneous compliance concerns, some additional operational and aesthetic issues are discussed.

TREATMENTS COVERED

- Granular Activated Carbon
- Microfiltration/Ultrafiltration
- Nanofiltration
- Other Microbial Removal Technologies

4.1 Granular Activated Carbon

The main benefit of granular activated carbon (GAC) is that it is effective in adsorbing and removing organic compounds from water. Removing organic matter lowers DBPs, taste and odor complaints, and microbial activity in the distribution system. Additionally, if GAC is used in series with a conventional filter, as illustrated below, systems may be able to receive additional *Cryptosporidium* removal credit under the LT2ESWTR. The main drawbacks to using GAC are the possibility of release of bacteria or carbon fines into the system, the possibility of chromatographic peaking, and its reaction with disinfectants. These issues are discussed in more detail in Section 4.1.2.



GAC can be used as an additional layer on top of an existing filter (GAC cap), or it can be placed in a separate contactor. Design will vary depending on whether it is used as a separate adsorber or if it is added as a filter cap. Its efficiency is determined by the contact time and the relative adsorption strength of the compounds that are to be removed. Some physical removal by filtration will occur in GAC beds as well.

4.1.1 Advantages of GAC

Advantages of GAC include:

- **Removes DBP precursors**
- **Can remove taste and odor compounds**
- **If used as a secondary filter, the system may be able to receive a 0.5-log *Cryptosporidium* removal credit**
- **Can be used as a biologically active filter after ozone to remove assimilable organic carbon (AOC)**

DBP Precursor Removal

DBP precursor removal before the addition of a disinfectant can significantly lower DBP production and ease compliance with the Stage 2 DBPR. GAC10, a GAC contactor with a 10 minute empty bed contact time (EBCT), is considered a best available technology (BAT) for the Stage 1 D/DBPR. GAC10 in combination with enhanced coagulation or enhanced softening or GAC20 are considered BATs for the Stage 2 DBPR. GAC has been found to reduce total organic carbon (TOC) by 30 to 90 percent depending on the contact time, the nature of the organic matter, and other parameters (USEPA 2003d and references therein). Generally, AOC is removed relatively quickly while other organic fractions take longer to remove.

Taste and Odor Removal

Because many taste and odor compounds are organic, the ability of GAC to adsorb organics also makes it a useful treatment technique in this respect. For example, GAC has been found to remove 30 to 40 percent of geosmin from drinking water (Youngsug et al. 1997). The removal efficiency was increased to 80 percent or more with the addition of ozone or peroxone. Similar reductions can be achieved for 2-methylisoborneol (MIB).

Cryptosporidium Removal

Systems can receive a 0.5-log *Cryptosporidium* removal credit for having a second set of filters in series in a conventional treatment plant. Both a GAC contactor and a conventional dual media filter with a GAC cap are eligible for this credit. In both cases the *Cryptosporidium* is removed through physical filtration onto the filter media. The filter must treat the entire

Using GAC in a second filter can:

- lower DBP precursors and other organics
- help meet the Stage 2 DBPR requirements
- achieve *Cryptosporidium* removal credit for the LT2ESWTR

flow of the plant to obtain the credit. Refer to the *LT2ESWTR Toolbox Guidance Manual* (USEPA N.d.e) for a description of rule requirements for receiving credit.

Removes AOC After Ozone

Ozonation often results in organic matter becoming AOC, which serves as a food source for microbes. This can cause difficulties with compliance with the Total Coliform Rule (TCR) and can lead to nitrification problems. GAC, acting as an adsorbent, can remove some AOC before it enters the distribution system.

Additionally, systems can take advantage of the high surface area per mass ratio of GAC and the fact that it adsorbs organics to operate the GAC filter in biologically active mode. By not having a disinfectant residual in the water passing through the filter and allowing biological growth, the system can achieve high removals of AOC. Using biologically active GAC filters after ozonation can reduce biological growth in the distribution system and lower DBPs. See Section 5.2 for further details on the use of biological filtration with ozone.

4.1.2 Potential Operational and Simultaneous Compliance Issues Associated with Using GAC

Potential issues associated with GAC use include:

- **Can limit the ability to prechlorinate;**
- **Previously adsorbed compounds can be released;**
- **Bacteria can be released;**
- **Carbon fines released from GAC filters can foul downstream processes;**
- **Chlorate can be formed when GAC comes in contact with chlorine dioxide; and**
- **Ammonia added before a GAC filter has been found to increase nitrification in the distribution system.**

This section briefly describes each of these issues and provides some suggestions for addressing them.

Limits Ability to Pre-chlorinate

Most disinfectants react quickly when they come into contact with GAC. This leads to a rapid loss of disinfectant residual, and in the case of chlorine, can lead to a faster depletion of the GAC.

Recommendations for Addressing this Issue

Systems should not use GAC filters at the same time as achieving CT for purposes of meeting disinfection requirements. Disinfectants should be added after the GAC filter. If the disinfectant addition points are moved, an evaluation of the CT throughout the plant must be made and any effects of moving the disinfection point, such as changes in coagulation and precipitation, pre-oxidation of contaminants, and growth of algae should be evaluated. If pre-oxidation is needed in treatment before GAC, alternative oxidants (e.g., potassium permanganate) or lower chlorine doses should be used so as not to carry a residual onto the GAC.

Release of Adsorbed Compounds

Organic materials adsorbed onto GAC will generally remain on the GAC until it is regenerated. But if a stronger adsorbing compound passes through the GAC when the GAC is relatively saturated, and the GAC does not have a significant number of free adsorption sites, weaker binding compounds can be expelled. It is possible for the concentration of these expelled compounds to be higher than the original concentration. This phenomenon is referred to as chromatographic peaking. Strongly adsorbing compounds that can have this effect include hydroxide used to adjust pH, or chloride as a byproduct of chlorination.

Recommendations for Addressing this Issue

To avoid chromatographic peaking and the desorption of contaminants from the GAC, pH adjustment should be made after the GAC filter. Chlorine should also generally be added after the GAC filter, both to avoid chromatographic peaking and to lower DBP formation. Any other sudden changes in water chemistry entering the GAC contactor should be avoided as well. If sudden swings in water chemistry are unavoidable, then GAC regeneration frequency should be increased and the filter effluent should be monitored carefully to prevent breakthrough of any contaminants.

Release of Bacteria

Studies have found that the average number of bacteria in the effluent of GAC filters can be significantly higher than influent levels (Parson et al. 1980; Klotz et al. 1976), indicating that heterotrophic bacteria growth may occur within the filters. For systems using GAC filtration that have inadequate post-GAC disinfection, bacteria may enter the distributon system. The primary concern with this potential bacteria release is the possible presence of pathogenic microorganisms. Other concerns include the possible presence of ammonia-oxidizing bacteria that could trigger a nitrification event if ammonia is present, and bacteria growth in distribution system biofilms.

Recommendations for Addressing this Issue

The amount of bacteria in the effluent of GAC systems can often be reduced by proper backwashing and GAC regeneration frequencies. However, some bacteria are still likely to be shed from GAC filters. Introducing a disinfectant residual in the filter itself is not recommended because most disinfectants react with GAC, spending the GAC and not penetrating the full depth of the bed. The best strategy to deal with bacteria shed from GAC filters is to add a disinfectant after the GAC filter.

Release of Carbon Fines

Small particles of carbon are usually present in GAC filters when they are first installed. These carbon fines appear gray or black and can cloud the water. If carbon fines from GAC filters are released into the product water, they can interfere with downstream treatment processes, particularly fouling of membrane filters and absorbing ultraviolet (UV) light in UV disinfection units, and cause poorer performance of these subsequent treatment steps.

Recommendations for Addressing this Issue

GAC filters should be placed after membrane or UV disinfection processes to avoid problems associated with the release of carbon fines. If this is not possible, proper backwashing procedures, good maintenance of the filter underdrains, and more frequent cleaning of the UV reactor or membrane unit can help to minimize the problem.

Formation of Chlorate

Chlorine dioxide, in addition to losing its residual, will form chlorate when it comes into contact with GAC. Chlorate can further react to form chlorite, a DBP regulated by the Stage 1 D/DBPR.

Recommendations for Addressing this Issue

Chlorine dioxide should be added after the GAC filters to avoid the formation of chlorate. If chlorine dioxide is used for pre-oxidation, it should be added far enough ahead of the GAC filter that no residual enters the contactor. If the treatment sequence first has conventional filtration and then the GAC filter, adding the chlorine dioxide prior to the first set of filters will usually solve the problem.

Nitrification with Chloramines

Systems that add ammonia prior to a GAC contactor have been found to have more frequent incidents of nitrification in the distribution system (Krasner et al. 2003). This may be caused by the ammonia stimulating growth of nitrifying bacteria on the GAC media and seeding the distribution system with these bacteria, though the research has not been conclusive.

Recommendations for Addressing this Issue

To reduce the potential for nitrification, systems using ammonia to form chloramines or to raise pH should add the ammonia after the GAC filters.

4.1.3 Recommendations for Gathering More Information

Read the Case Study

For more information on simultaneous compliance issues associated with GAC and how to address them, see ***Case Study #7 - Granular Activated Carbon for TOC removal*** starting on page B-39 of Appendix B. This case study describes how a utility used GAC to address high levels of atrazine in its source water and high TTHM levels in its finished water. The system was able to reduce their atrazine levels 30 to 60 percent and their UV_{254} levels 20 percent six months after installing the GAC cap. The greatest operational issue faced by the system was a build up of inorganic precipitates on the GAC filter, and occasional taste and odor episodes.

See Additional References

Readers can turn to Chapter 7 for more references on this topic. Section 7.1.1 includes general references on water treatment, Section 7.1.2 contains references on controlling DBP formation, and section 7.1.9 contains references on GAC use.

Consider Additional Monitoring

The following are some suggestions for additional monitoring that may benefit water systems implementing GAC. Note that the purpose of these monitoring suggestions is specifically to address and prevent potential simultaneous compliance issues. Water system managers should discuss process control monitoring with the GAC manufacturer or their engineer.

- ✓ Periodic monitoring of volatile organic chemicals (VOCs) and synthetic organic chemicals (SOCs), as appropriate, in water leaving the GAC unit to detect breakthrough and desorption of contaminants;

- ✓ Turbidity or particle count measurements of the GAC effluent, especially when new or re-activated carbon is first being used; and

- ✓ Heterotrophic plant counts (HPC) in water leaving the GAC units to watch for an increase in bacteria numbers.

Consider Other Tools

In addition to water quality monitoring, there are additional tools described in Chapter 6 to help systems evaluate and improve their current water system in relation to the compliance issues they may face when modifying their treatment practices. Examples of tools that can be used when GAC is used for Stage 2 DBPR compliance include:

- The AwwaRF report “Prediction of GAC Performance Using Rapid-Small Scale Column Tests” (Crittenden 1989) that describes the use of RSSCT techniques to predict full-scale GAC’s useful lifetime when it is used to remove dissolved organic matter from a drinking water source. This report also demonstrates how to use pilot-scale testing data to further refine the RSSCT prediction;

- The "Handbook of Public Water Systems" (HDR Engineering, Inc. 2001) which provides detailed engineering design aspects of various drinking water treatment processes including granular activated carbon;

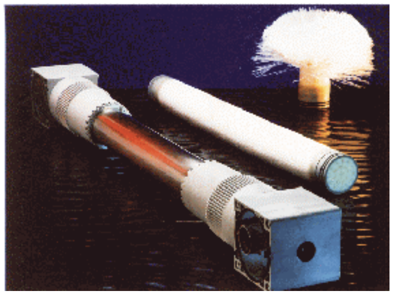
- EPA's ICR Treatment Study Database contains the results of 63 pilot studies of GAC plants. It can be found on the web at: www.epa.gov/safewater/data/icrtreatmentstudies.html;

- The second version of "Water Treatment Plant Model" (USEPA 2001i) developed by EPA in 2001 that assists utilities with implementing various treatment changes, while maintaining adequate disinfection and meeting the requirements of Stage 2 DBPR; and

- Various cost estimation models that can be used to estimate the cost of constructing and operating a new GAC facility (See Section 6.3.7).

Readers are encouraged to read through Chapter 6 before making any final compliance decisions.

4.2 Microfiltration/Ultrafiltration



Microfiltration/Ultrafiltration (MF/UF) is a low-pressure membrane technology. The membranes remove particulate matter larger than the membrane pore size. MF membranes generally operate at slightly lower pressure and have larger pore sizes than UF membranes. In some cases, MF/UF membranes will be used together, with the MF membranes acting as a pre-filter for the UF membranes. MF/UF units are often supplied on skid mounted assemblies that can easily be installed and have high degrees of automation.

4.2.1 Advantages of MF/UF

Advantages of MF/UF include:

- **Removes bacteria and protozoa**
- **Can lower DBPs by allowing lower disinfectant doses**
- **Can remove particulate arsenic**

An advantage of MF/UF is that it can achieve high removal rates of bacteria, *Giardia* and *Cryptosporidium*. This allows a system to lower its disinfectant dose and possibly reduce its finished water DBP concentrations.

Bacteria and Protozoa Removal

Membrane processes remove all particles larger than the pore size of the membrane, provided the membrane integrity is not compromised. Bacteria, *Cryptosporidium* oocysts, and *Giardia* cysts can all be reliably removed by MF/UF. Although MF membranes do not generally remove viruses, some UF membranes can remove viruses. MF/UF units that are challenge-tested before installation and undergo membrane integrity tests qualify for additional *Cryptosporidium* removal credit as determined based on testing results. See the *LT2ESWTR Toolbox Guidance Manual* (USEPA N.d.e) for more information. Systems should also consult with their state to determine applicable credits and requirements.

If surface water systems use MF/UF instead of chemical disinfection to get inactivation/removal credit, they must add a disinfectant such as chlorine or chloramines to maintain a disinfectant residual in the distribution system.

DBP Reduction

Because MF/UF can achieve high levels of microbial removal, systems installing MF/UF can lower their disinfectant dose and still achieve the same level of microbial protection. The lowered disinfectant dose may result in lower DBPs and aid in meeting Stage 2 DBPR requirements.

Arsenic Removal

MF/UF membranes do not have a small enough molecular cut-off weight to remove dissolved or colloidal arsenic. They can, however, remove particulate arsenic. The removal will depend on the size distribution of particles the arsenic is bound to and the pore size of the membrane. A coagulation step prior to the membranes will help to improve arsenic removal. Electrostatic repulsion can also help increase arsenic removal in MF/UF systems. The increase in removal will depend on the charge of the membrane, the oxidation state of the arsenic, and the pH of the water. Removal rates have been shown to vary between 5 and 70 percent (Amy, et al. 2000).

4.2.2 Potential Operational and Simultaneous Compliance Issues Associated with MF/UF

Potential issues associated with MF/UF use include:

- **Can be fouled by organics and minerals**
- **Increased loss of process water**
- **Additional training required**

This section provides brief descriptions of these issues and suggestions for minimizing their impacts.

Membrane Fouling

Membranes can be fouled by organic matter, iron, manganese, and carbonate deposits. Sources of these fouling compounds include source water and treatment chemicals. Ground water systems that do not treat their water before it passes through the MF/UF unit may have particular problems with iron, manganese, and other minerals. This is especially true if the ground water is anoxic and is exposed to the atmosphere during pumping or an aeration process, resulting in dissolved minerals settling out.

<u>Recommendations for Addressing this Issue</u>

If TOC is high after filtration, it can be lowered through other pretreatment techniques, including:

- **Pre-sedimentation**
- **Enhanced coagulation**
- **GAC filtration (less often)**

Systems with high TOC can reduce fouling by placing the MF/UF after existing sedimentation and/or filtration processes. If TOC is high even after filtration, TOC can be lowered by adding other pretreatment techniques. Pretreatment to lower TOC levels includes: pre-sedimentation, enhanced coagulation, and, less often, GAC filtration. TOC removal can often be accomplished by good coagulation before the membranes. If iron-based coagulants are used, jar testing should be carried out to ensure optimal dosing and settling, because iron-based coagulants can foul some membranes. GAC filtration removes much of the organic matter, although not all organic compounds are adsorbed easily. A cartridge filter may need to be installed before the MF/UF unit, however, to prevent carbon fines from entering the membrane unit.

Systems that aerate their ground water to oxidize iron, manganese or other compounds should remove any precipitated minerals before the water reaches the MF/UF unit to prevent fouling. The manufacturer of the MF/UF unit and other utilities with experience using the same units should be consulted before a system makes any changes to the chemistry of the treated water, since many treatment chemicals can also foul membranes.

Regardless of the pretreatment involved and the quality of the water, membranes will eventually foul and will need to be cleaned. Cleaning the membranes will improve performance and prolong membrane life. The appropriate length between cleanings can be determined by monitoring the long-term decrease in productivity and backwash efficiency.

Loss of Process Water

Membrane processes produce reject streams as well as backwash water. Therefore, the amount of wastewater that has to be handled can be higher than that produced during conventional filtration. Although improvements have been made in efficiency, some water systems lose as much as 15 percent of the process water as a waste stream. Other membrane projects have been bid with approximately 92 percent recovery in summer and 90 percent recovery in winter (Sarah Clark, personal communication). In a recent survey of MF/UF systems, however, the median value for feed water recovery was 95 percent (Adham et al. 2005).

Recommendations for Addressing this Issue

To handle the higher quantities of process water produced by MF/UF units, systems may need to increase the capacity of their wastewater storage and residuals processing facilities. This is especially true of systems that recycle their reject water.

To minimize the lost water, systems may also be able to recycle some of the reject stream if the membranes are added onto a conventional treatment train. In this case, the recycle must be sent to the head of the plant according to the Filter Backwash Recycling Rule (FBRR), unless the State approves an alternate location. The effect of additional particle loading should be taken into account when determining coagulant dosing and filter loading rates.

Additional Training Required

MF/UF membranes are significantly different to operate than other water treatment units. The control parameters are different; the State will determine the parameters that the system must monitor to demonstrate regulatory compliance.

Recommendations for Addressing this Issue

Systems should consult with their state to determine what parameters will need to be monitored for approval and regulatory compliance. Systems should also work with the state and the vendor to provide adequate training for operators.

4.2.3 Recommendations for Gathering More Information

See Additional References

Readers can turn to chapter 7 for further references on this topic. Section 7.1.1 contains general references on water treatment, and section 7.1.10 contains references on membranes, including MF/UF.

Consider Additional Monitoring

The following are some suggestions for additional monitoring that may benefit water systems implementing MF/UF. Note that the purpose of these monitoring suggestions is specifically to address and prevent potential simultaneous compliance issues. Water system managers should discuss process control monitoring with the MF/UF manufacturer and other experienced utilities.

- ✓ Periodic monitoring of iron, manganese, and other minerals in the water entering the MF/UF unit to detect an increase in minerals that may need to be addressed by pre-treatment;

- ✓ Particle counting to indirectly monitor membrane integrity and determine if a direct integrity test should be conducted;

- ✓ Total organic carbon (TOC) in the membrane unit’s influent and effluent to track removal performance;

- ✓ Heterotrophic plate counts (HPC) in the membrane unit’s effluent if membrane integrity is lost; and

- ✓ Membrane autopsies on any failed membranes to determine the cause of failure and determine possible corrective actions.

Consider Other Tools

In addition to water quality monitoring, there are additional tools available in Chapter 6 to help systems evaluate and improve their current water system in relation to the compliance issues they may face when modifying their treatment operations. Examples of tools that can be used when MF/UF membranes are used for LT2ESWTR and Stage 2 DBPR compliance include:

- The “Membrane Filtration Guidance Manual” (USEPA 2005b) provides general recommendations for membrane pilot testing;

- The AwwaRF report "Integrated Membrane Systems" (Schippers et al. 2004) that provides guidance on the selection, design, and operating an integrated membrane system that can function as a synergistic system for removing microbiological contaminants and DBP precursors;

- The AwwaRF report "Integrating Membrane Treatment in Large Water Utilities" (Brown and Hugaboom 2004) that provides guidance to issues related to the integration of low pressure membranes into larger water treatment facilities, including membrane layout, piping, cost comparison, and operations and maintenance;

- EPA's Environmental Technology Verification Program collects performance data on many environmental technologies, including MF/UF. Reports for each technology can be found on the website at: http://www.epa.gov/etv/verifications/verification-index.html;

- The second version of "Water Treatment Plant Model" (USEPA 2001i) developed by EPA in 2001 that assists utilities with implementing various treatment changes while maintaining adequate disinfection and meeting the requirements of Stage 2 DBPR; and

- Various cost estimation models, such as WTCost©, 2003, that can be used to estimate the cost of implementing a new membrane facility (see Section 6.3.7).

Readers are encouraged to read through Chapter 6 before making any final compliance decisions.

4.3 Nanofiltration

Nanofiltration is a membrane process that physically removes contaminants from water that are larger than the pore size of the membranes. Nanofiltration uses pore sizes and operating pressures that fall between those of UF and reverse osmosis.

Nanofiltration's main advantage over MF/UF is that it can remove virtually all particulate matter as well as larger dissolved compounds, including dissolved organic matter. In addition to meeting all removal requirements for pathogens, it leads to lower DBPs by removing DBP precursors. Its main disadvantages are that it can be fouled by organics or precipitated minerals, it can increase corrosiveness of the water, it has a large reject stream, and it requires additional training.

4.3.1 Advantages of Nanofiltration

Some advantages of nanofiltration include:

- **Significant removal of bacteria, protozoa, and viruses**
- **Can remove organics that act as DBP precursors**
- **Removes arsenic**

Nanofiltration's main advantage is that it can remove virtually all particulate matter as well as larger dissolved compounds, including some dissolved organic matter.

Significant Removal of Bacteria, Protozoa, and Viruses

Nanofiltration has small pore sizes that exclude essentially all particulate matter, as long as the membrane is intact. Therefore, nanofiltration units that are capable of being integrity tested may receive credit for *Cryptosporidium* removal under LT2ESWTR.

Removes DBP Precursors

Nanofiltration can remove dissolved organic compounds that serve as DBP precursors. When little or no bromide ion was present in the source water, nanofiltration membranes with molecular weight cutoffs (MWCOs) of 400 to 800 daltons were shown to effectively control DBP formation (Laine et al. 1993). Nanofiltration with the same pore size produced higher bromoform concentrations when bromide was present, although total THMs decreased. Membranes with smaller pore sizes controlled bromoform formation better but required pretreatment to avoid membrane fouling.

DBP formation may be lowered even further if the state allows the system to reduce its disinfectant dose and the amount of primary disinfection because of the high microbial removal rate of the nanofiltration units. When this is the case, nanofiltration can accomplish both high pathogen removal and low DBP formation.

Removes Arsenic

Nanofiltration membranes can remove both dissolved and particulate arsenic through size exclusion and electrostatic repulsion. Removal rates will depend on the surface charge of the membrane, speciation of the arsenic, dissolved organic concentration, and pH. Oxidized arsenic (V) is removed much more efficiently than reduced arsenic (III). Single element tests have found rejection rates for arsenic (V) between 80 and 95 percent (Amy et al. 2000). Other tests on pilot scale membranes have found the removal can decrease to between 65 and 75 percent over time (Malcolm Pirnie 1992, Chang et al. 1994).

4.3.2 Potential Operational and Simultaneous Compliance Issues Associated with Nanofiltration

Potential issues associated with nanofiltration include:

- **Can be fouled by organics and precipitated minerals**
- **Can increase corrosiveness of water**
- **Issues with reject stream**
- **Additional training required**

This section briefly describes these issues and provides suggestions for addressing their impacts.

Membrane Fouling

Organics and precipitating minerals can foul nanofiltration membranes and cause them to operate inefficiently, shortening their useful life. Fouling also increases operating pressures and causes more frequent backwashing, which raises operating expenses. Fouling agents can come from the source water or be introduced as part of the treatment process. Ground waters that are not filtered before the water passes through the membranes may have more difficulties with fouling due to high mineral concentrations.

<u>Recommendations for Addressing this Issue</u>

If nanofiltration membranes are being used in conjunction with a conventional filtration plant, the membranes should be placed after the filters to allow for the maximum removal of fouling compounds before water passes through the membranes. Treatment processes that can change the chemistry of the water should be located downstream of the nanofiltration unit if possible. These include pH adjustment and disinfectants. Systems should bear in mind, however, that nanofiltration generally works better at acid pH.

If the treatment train in place is not sufficient to reduce fouling compounds, some sort of pretreatment will be required. The simplest pretreatment is often adding a cartridge filter before the membranes. If the water being treated is anoxic ground water, aeration may be considered to oxidize and precipitate any minerals before the cartridge filter. Other options for pretreatment include enhanced coagulation and pre-sedimentation. If enhanced coagulation is used, jar testing should be conducted to optimize the dose to ensure that unflocculated coagulant does not enter the membrane unit.

Regardless of the pretreatment involved and the quality of the water, membranes will eventually foul. Cleaning the membranes is necessary for improving performance and prolonging membrane life. The appropriate length between cleanings can be determined by monitoring the long-term decrease in productivity and back wash efficiency.

If coagulants or disinfectants are added prior to membranes, the system should consult the membrane manufacturer and other experienced utilities to determine if the chemicals will cause fouling or otherwise damage the membranes.

Increase Corrosiveness

Nanofiltration can soften water by removing minerals such as calcium and magnesium. It can also result in a lowering of the pH of the water. The less alkaline, lower pH water will be more corrosive to distribution system piping and other process equipment, while not providing a passivating layer as harder water can. The lower pH can also shift the carbonate equilibrium to produce carbon dioxide. In groundwaters, hydrogen sulfide can also pass through the membranes. All these factors combine to increase the corrosiveness of the water.

Increased corrosiveness can cause problems with Lead and Copper Rule (LCR) compliance. Depending on the magnitude of the pH drop, it may also affect the disinfection efficiency of the secondary disinfectant as well. See Section 3.4 for more discussion of disadvantages associated with lowering water pH. It is also possible that the removal or minerals such as calcium can be so significant as to cause the water to taste significantly different to customers, possibly generating customer complaints.

Recommendations for Addressing this Issue

The simplest way to avoid problems associated with a low pH is to adjust the pH after the membranes. The fittings for the membrane unit, as well as any equipment between the nanofiltration unit and the point where the pH is readjusted, should be made of materials that can resist the lower pH of the water. Water systems should also adjust the alkalinity after nanofiltration to prevent changes in pH in the distribution system that can enhance corrosion. Passive treatment technologies, such as neutralizing filters or limestone contactors, are one way to achieve a good pH and carbonate balance in membrane-treated waters.

Aeration may help to remove any sulfide or carbon dioxide accumulated as well as raise oxygen levels to oxidize the sulfide to sulfate. Adding a disinfectant after the membranes can also aid in oxidizing sulfide.

Another approach some systems have taken is to only pass part of the influent stream through the NF unit and blend that NF product with water that has not received NF treatment. However, this negates the microbial treatment credit of NF and would require an alternative microbial treatment on the stream not treated by NF.

Issues with Reject Stream

Membrane processes produce a reject stream as well as backwash water. Therefore, the amount of wastewater that has to be handled can be significantly higher than that produced during conventional filtration. Although improvements have been made in efficiency, losing 10 to 20 percent of the process water as a waste stream is not unusual. The amount of process water lost can be reduced by a second membrane unit in series with the first unit.

Due to the small pore size associated with nanofiltration, other feed water constituents will also be removed. As a result, divalent salts, some metals, and some soluble organic carbon may be concentrated in the waste stream. This may increase the cost associated with disposing of the waste stream compared to disposal costs associated with MF, UF, and conventional treatment processes. If regulatory limits or plant locations prohibit sending the waste stream to a receiving body or wastewater treatment plant, costs for waste handling and disposal can be substantial.

Recommendations for Addressing this Issue

To handle the higher quantities of waste water produced by nanofiltration units without causing upset to the system, utilities may need to increase the capacity of their wastewater storage and residuals processing facilities. This is especially true of systems that recycle their reject water. If water is recycled, the Filter Backwash Recycling Rule (FBRR) requires that it be recycled to the head of the plant unless the State approves an alternate location.

Water systems using nanofiltration will most likely need to increase the amount of water they withdraw from their source to account for their process water losses. This could be an issue in arid regions where water is scarce and water restrictions are in place.

Disposal of the reject stream to the ocean may be a good option since the salinity of brine is typically not an issue. Otherwise systems will need to discuss the possibility of disposing of the brine to the sanitary sewer which may have limits on brine or on certain metals and may involve additional charges.

Additional Training Required

NF membranes are significantly different to operate than other water treatment units. The control parameters are different; the State will determine the parameters that the system must monitor to demonstrate regulatory compliance.

Recommendations for Addressing this Issue

Systems should consult with their state to determine what parameters will need to be monitored for approval and regulatory compliance. Systems should also work with the state and the vendor to provide adequate training for operators.

4.3.3 Recommendations for Gathering More Information

Read the Case Study

For more information on simultaneous compliance issues associated with nanofiltration and how to address them, see ***Case Study #8 - Nanofiltration Membrane Technology for TOC Removal*** starting on page B-43 of Appendix B. This case study describes the challenges faced by one PWS switching to nanofiltration in response to growing demands for water and the implementation of new drinking water standards. Specifically, the NF plant would facilitate the removal of hardness, color, TOC, and its related chlorinated DBPs. The greatest operational issue involved numerous leaks in the acid feed system, and sagging in the micron cartridge filter housings and the string-wound filter.

See Additional References

Readers can turn to chapter 7 for further references on this topic. Section 7.1.1 contains general references on water treatment, and section 7.1.10 contains references on membranes, including NF.

Consider Additional Monitoring

The following are some suggestions for additional monitoring that may benefit water systems implementing nanofiltration. Note that the purpose of these monitoring suggestions is specifically to address and prevent potential simultaneous compliance issues. Water system managers should discuss process control monitoring with the manufacturer of their nanofiltration units or their engineer.

- ✓ The pH of water leaving the nanofiltration unit should be monitored to ensure that 1) CT is being calculated accurately; and 2) chemical dosages for corrosion control are correct;

- ✓ Hardness and alkalinity of water leaving the nanofiltration unit should be measured to ensure that chemical dosages for corrosion control are correct;

- ✓ TOC in the NF influent and effluent should be monitored to measure removal effectiveness;

- ✓ Particle counting should be conducted to indirectly monitor membrane integrity and determine if a direct integrity test;

- ✓ HPC should be measured in the NF effluent to identify breakthrough;

- ✓ Membrane autopsies should be performed on any failed membranes to determine the cause of failure and determine possible corrective actions; and

- ✓ Taste and odor quality should be measured to ensure customer acceptance.

Consider Other Tools

In addition to water quality monitoring, there are additional tools available in Chapter 6 to help systems evaluate and improve their current water system in relation to the compliance issues they may face when modifying their treatment operations. Examples of tools that can be used when nanofiltration is used for Stage 2 DBPR compliance include:

- The AwwaRF report “Integrated Membrane Systems” (Schippers et al. 2004) that provides guidance on the selection, design, and operation of an integrated membrane system that can function as a synergistic system for removing microbiological contaminants and DBP precursors;

- The AwwaRF report “Integrating Membrane Treatment in Large Water Utilities” (Brown and Hugaboom 2004) that provides guidance on issues related to the integration of low pressure membranes into larger water treatment facilities, including membrane layout, piping, cost comparison, and operations and maintenance;

- The AwwaRF report “NOM Rejection by, and Fouling of, NF and UF Membranes” (Amy et al. 2001) that provides information on the selection of appropriate nanofiltration membranes to achieve high NOM rejection, and also presents information on how water quality (such as the presence of calcium and pH) and operational condition might affect NOM rejection by NF membranes;

- EPA’s Environmental Technology Verification Program collects performance data on many environmental technologies, including nanofiltration. Reports for each technology can be found on the website at: http://www.epa.gov/etv/verifications/verification-index.html;

- EPA’s ICR Treatment Study Database contains the results of 36 pilot studies of nanofiltration plants. It can be found on the web at: www.epa.gov/safewater/data/icrtreatmentstudies.html;

- The second version of “Water Treatment Plant Model” (USEPA 2001i) developed by EPA in 2001 that assists utilities to implement various treatment changes while maintaining adequate disinfection and meeting the requirements of Stage 2 DBPR; and

- Various cost estimation models, such as WTCost©, 2003, that can be used to estimate the cost of implementing a new membrane facility (see Section 6.3.7).

Readers are encouraged to read through Chapter 6 before making any final compliance decisions.

4.4 Other Microbial Removal Technologies

Other microbial removal technologies can be used to meet LT2ESWTR requirements. All of the technologies listed below use some type of filtration media to remove *Cryptosporidium* oocysts and other microbes from drinking water. The LT2ESWTR specifies minimum design and implementation criteria for receiving various levels of *Cryptosporidium* treatment credit. The *LT2ESWTR Microbial Toolbox Guidance Manual* (USEPA N.d.e) will provide additional guidance for each technology. The state should also be consulted on the requirements for obtaining pathogen removal credit for these technologies. Although these technologies are not expected to present significant compliance problems with other drinking water regulations if implemented properly, there are operational issues that utilities should consider if they use these options. These technologies are:

Bank Filtration
Bank filtration uses vertical or horizontal wells drilled near a riverbank. The riverbed and material between the well and the riverbank act as the filtration media. It is generally used as pretreatment for an existing treatment plant.

The *LT2ESWTR Toolbox Guidance Manual* will provide more information on the advantages and disadvantages of different *Cryptosporidium* oocyst removal technologies.

Improved Filter Performance
Improved filter performance results from optimizing existing filtration to achieve consistently low filter effluent turbidity. In order to meet the lower finished water turbidity requirements, systems 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* (USEPA 1999d) discusses many design and operational aspects water systems should consider for achieving low effluent turbidity.

Bag Filtration
Bag filtration is a pressure driven filtration process using a fabric filter media. Flow is from inside the vessel to outside the vessel.

Cartridge Filtration
Cartridge filters are pressure driven filtration devices that have rigid or semi-rigid filter media housed in pressure vessels. Water flows from outside the cartridge filter's vessel to the inside.

Second Stage Filtration
Second stage filtration involves placing a second set of granular media filters in series with an existing set of filters. The media can be rapid sand filters, slow sand filters, or GAC filters.

Slow Sand Filtration
Slow sand filtration uses sand with a biologically active top layer as a filtration media and gravity as the driver at relatively low loading rates.

Diatomaceous Earth Filtration
Diatomaceous earth (DE) filtration, often referred to as “pre-coat” filtration, uses a layer of diatomaceous earth placed on a permeable cover or porous filter septum to filter water. DE filters are operated as either pressure filters or vacuum filters.

This section briefly describes issues associated with the use of these technologies, provides suggestions for addressing those issues, and recommends additional monitoring that can be conducted.

4.4.1 Advantages

There are several advantages to these microbial removal technologies. The following paragraphs list these advantages and briefly discuss which of these technologies provide each advantage.

- **Ease of use (bag filtration, cartridge filtration, bank filtration);**
- **Removal of *Cryptosporidium* and other pathogens (all technologies listed); and**
- **Removal of other contaminants/ DBP precursors (bank filtration, second stage filtration, slow sand filtration).**

Most operators are familiar with filtration. Second stage filtration, DE, and slow sand filtration can all be easily implemented by any system familiar with conventional filtration. Cartridge and bag filters are even easier to use as the only routine maintenance required is replacing the cartridge or bag when a pre-set trigger is reached, either a pressure drop or a given time.

All of these technologies will remove matter that is larger than the filter's effective pore size. Therefore, in addition to *Giardia* cysts and *Cryptosporidium* oocysts, they will remove some other microbial pathogens as well.

Some of these technologies can also be effective in removing DBP precursors and other organic chemicals. Slow sand filtration can remove some DBP precursors. Second stage filtration can offer additional DBP precursor removal, especially when GAC is used as the second filter media. Bank filtration often provides additional DBP removal through biological activity in the riverbank (Weiss et al. 2003).

4.4.2 Potential Operational and Simultaneous Compliance Issues

The disadvantages of these microbial removal technologies include:

- **Hydraulic problems or scouring (all technologies listed);**
- **Clogging (cartridge filters, bank filtration);**
- **Increased residuals/ backwash (second stage filtration, increased filter performance);**
- **Iron/manganese problems (bank filtration); and**
- **Filter fouling (bag filters, cartridge filters).**

With careful planning, many of the disadvantages of these technologies can be overcome. The following paragraphs briefly describe steps that can be taken to mitigate these disadvantages.

Hydraulic Problems or Scouring

All of these technologies can add significant hydraulic head to a plant’s hydraulic profile. Changes in head, especially when filters are restarted, can disturb the filter and cause poor performance.

Bank filtration can experience riverbank scouring during periods of high flow. The riverbank scour can remove much of the finer grained sediment responsible for a portion of the removal associated with this filtration method.

Large changes in flow to bag filters or intermittent operation can cause stress on the seams of the bag filter and lead to premature failure.

<u>Recommendations for Addressing this Issue</u>

Hydraulic loss due to additional filtration can often be overcome by conducting a hydraulic profile of the plant. Pumps can be installed to add additional head. The pumps should be installed and operated in such a way as to not cause hydraulic disturbances to surrounding processes, such as flocculation. Installing additional storage upstream of filtration is also a way to smooth out hydraulic disturbances before they upset the filtration. Filtering to waste can eliminate some of the problems associated with filter start-up.

Clogging

Bank filtration can also be subject to clogging by biomass growth in the pores or settling of finer grained material in the pores. Although this may increase removal efficiency of contaminants, it will increase pumping costs and drop yield. If too much coagulant is used before cartridge filters, they can also clog, necessitating more frequent replacement and higher costs.

Recommendations for Addressing this Issue

Some types of clogging in bank filtration can be avoided by proper siting of the wells. Changes in chemistry in the aquifer that could precipitate minerals and areas of high sedimentation should be avoided. Otherwise, some clogging is inevitable and even necessary. Systems may have to account for this by designing for higher pumping rates than necessary or installing multiple wells.

Increased Residuals or Backwashing

Many of these technologies can create disposal problems. Cartridge and bag filters have to be disposed of periodically. Second stage filtration will generate additional backwash water and residuals that will need to be disposed. Practices to improve turbidity to increase filter performance can also lead to increased residuals and backwash water. Systems considering replacing their filter bed media as part of an effort to improve filter performance should consider whether there will be challenges associated with the disposal of old media that may contain high concentrations of metals or other contaminants.

If significant amounts of additional backwash and residuals are generated, a system may need to change its residuals disposal procedures. This may include treating backwash water through the addition of coagulant, or adding new sludge dewatering technologies or other residuals handling equipment.

Recommendations for Addressing this Issue

To handle the higher quantities of process water produced by backwashing filter units, systems may need to increase the capacity of their wastewater storage and residuals processing facilities. This is especially true of systems that recycle their reject water. Manufacturers can also be consulted for disposal recommendations for bag and cartridge membranes.

Iron and Manganese Problems

Bank filtration can result in elevated levels of iron and manganese if the portion of the aquifer the wells draw from is anoxic. This will allow reduced manganese and iron to dissolve and enter the water.

Recommendations for Addressing this Issue

If bank filtration is carried out through an anoxic zone, aeration may need to be added to oxidize dissolved iron, manganese, and any other reduced chemical species that could cause operational or aesthetic problems. Adding a pre-oxidant such as permanganate, ozone, or chlorine can also oxidize iron and manganese.

Filter Fouling

Cartridge and bag filters can be fouled by biofilm if there is insufficient disinfectant residual present to control the growth. This can increase the pressure loss across the filter and shorten filter life.

Recommendations for Addressing this Issue

Adding disinfectant before the filters can prevent biofilm growth from clogging bag and cartridge filters. Systems should evaluate the potential for DBP formation before taking this step. Systems should also confirm that the filter media is compatible with the disinfectant.

4.4.3 Recommendations for Gathering More Information

See Additional References

Readers can turn to chapter 7 for additional references on this topic. Section 7.1.1 includes general references on water treatment, including filtration, Section 7.1.8 includes references on enhanced coagulation and softening, and Section 7.1.11 includes references on riverbank filtration.

Consider Additional Monitoring

Monitoring is important for determining the performance of these technologies. It can provide a good indication of performance and help make operating determinations such as when to backwash or replace filters.

- ✓ Turbidity is used to determine filter performance as well as warn that a filter needs to be backwashed. Monitoring of individual and combined filter effluents is required for conventional filters. Even if the filter is installed as a second filter or in series with another treatment technology, turbidity monitoring should be conducted;

- ✓ Particle counters can also provide useful information, and can frequently determine breakthrough before turbidity measurements can;

- ✓ Flow measurements help to spot potential hydraulic upset and adjust loading rates appropriately;

- ✓ Pressure measurements are used to indicate how frequently a system needs to backwash or whether filter media needs to be replaced; and

- ✓ Streaming current detectors can be used to detect the charge on particles and optimize coagulant dose.

Consider Other Tools

In addition to water quality monitoring, there are additional tools available in Chapter 6 to help systems evaluate and improve their current water system in relation to the compliance issues they may face when modifying their treatment operations. Examples of tools that can be used when implementing the other microbial removal technologies described in this section include:

- The AwwaRF report "Evaluation of Riverbank Filtration as a Drinking Water Treatment Process" (Wang, Hubbs and Song 2002) that provides general information on the design and operation of a riverbank system that can be used for the removal of DBP precursors and microbial contaminants;

- EPA's Environmental Technology Verification Program collects performance data on many environmental technologies, including diatomaceous earth, cartridge, and bag filters. Reports for each technology can be found on the website at: http://www.epa.gov/etv/verifications/verification-index.html;

- The second version of "Water Treatment Plant Model" (USEPA 2001i) developed by EPA in 2001 that assists utilities with implementing various treatment changes, while maintaining adequate disinfection and meeting the requirements of Stage 2 DBPR;

- Various cost estimation models that can be used to estimate the costs of designing, constructing, and operating one of the technologies described above (see Section 6.3.7) ;and

- The Partnership for Safe Water has many resources available for optimizing filter performance. More information can be obtained at their website at: http://www.awwa.org/science/partnership/.

Readers are encouraged to read through Chapter 6 before making any final compliance decisions.

5 Alternative Disinfection Strategies

As discussed in previous chapters, some water systems, after improving and optimizing current operations, will still need to install a new type of treatment to comply with the Stage 2 DBPR and LT2ESWTR. Some systems may consider switching to an alternative disinfectant for either primary or residual disinfection (or both). This chapter describes potential simultaneous compliance issues associated with using any of the following alternative disinfectants:

- Chloramines
- Ozone
- Ultraviolet light (UV)
- Chlorine dioxide

Suggestions are also provided for how systems can mitigate simultaneous compliance and operational issues that are identified.

In addition, Section 5.5 of this chapter discusses different possible combinations of primary and residual disinfectants, and simultaneous compliance issues that may arise as a result of using the disinfectants in combination.

ALTERNATIVE DISINFECTION STRATEGIES COVERED

- **Chloramine**
- **Ozonation**
- **Ultraviolet Light**
- **Chlorine Dioxide**
- **Primary and Residual Disinfectant Use**

5.1 Chloramines

Chloramines are formed when free chlorine reacts with ammonia and may be present as monochloramine, dichloramine, and/or trichloramine. The chloramine compounds react more slowly than free chlorine and as a result, they form fewer DBPs and are more persistent in the distribution system. Some studies have shown that chloramine compounds can penetrate biofilms more effectively than free chlorine. Monochloramine is generally considered the preferred species for disinfection purposes because of its biocidal properties, relative stability, and infrequent taste and odor problems (Kirmeyer et al. 2004a). Because monochloramine is a weaker disinfectant than free chlorine, it is more frequently used as a residual disinfectant in the distribution system. If not properly controlled, the use of chloramines can lead to nitrification episodes in the distribution system and may cause taste and odor issues, loss of disinfectant residual, and other problems.

5.1.1 Advantages of Chloramines

The use of chloramination to comply with the Stage 2 DBPR presents numerous benefits in terms of implementation and operation. Advantages include:

- **Lower DBP formation**

- **More persistent than free chlorine residuals**
- **Biofilm control in the distribution system**
- **May reduce occurrence of *Legionella***

Lower DBP Formation

Compared to free chlorine, chloramines react more slowly with organic matter resulting in lower concentrations of total trihalomethane (TTHM) and haloacetic acid (five) (HAA5). Although detectable concentrations of mono- and dichloroacetic acids can be produced, these are generally significantly lower than corresponding concentrations produced by free chlorine. Replacing chlorine with chloramines as a secondary disinfectant typically reduces TTHM levels 40 to 80 percent. Depending on the system's water quality, the actual TTHM reduction can vary from 10 to 95 percent (Kirmeyer et al. 2004a).

If chlorine is added to the water before ammonia, the byproducts associated with the use of free chlorine can be formed, although additional formation will be significantly retarded once the ammonia has been added. Because free chlorine is a much more effective disinfectant for viruses, surface water systems generally add chlorine early enough in the treatment train so that CT requirements for viruses are achieved before the ammonia is added.

More Persistent than Free Chlorine Residuals

Chloramines have a lower oxidation-reduction potential and a slower reaction time than free chlorine, so they are less likely to be consumed by reactions with organics and reduced metals. Therefore, they are longer lasting in the distribution system and are generally more persistent than a free chlorine residual. This characteristic helps to protect distribution system water quality, particularly in areas with long detention times. It also helps maintain compliance with the Surface Water Treatment Rule (SWTR)'s requirement to maintain a disinfectant residual.

Biofilm Control in the Distribution System

Studies have shown that chloramine compounds are better able to penetrate the biofilm layer and inactivate attached organisms because they are more limited than chlorine in the types of compounds with which they will react (USEPA 1992a; Jacangelo, Olivieri, and Kawata 1987). LeChevallier, Cawthorn, and Lee (1988a, 1988b) found that chloramines were more effective at inactivating biofilm organisms than free chlorine. LeChevallier, Lowry, and Lee (1990) also found that, in iron pipes, 3 to 4 mg/L doses of free chlorine did not control biofilm growth. Chloramines, however, did control biofilm growth at doses starting at 2 mg/L. Recent research suggests that the factors affecting biofilm growth and disinfection are complicated and may depend on many factors, thus varying between systems (Ollos, Huck, and Slawson 2003).

May Reduce Occurrence of Legionella

Use of monochloramine in water supplies may reduce the occurrence of *Legionella* bacteria and incidence of Legionnaires' disease. Flannery et al. (2006) conducted a 2-year study to evaluate whether converting from chlorine to monochloramine for water disinfection would decrease *Legionella* colonization of hot water systems. Water and biofilm samples from 53 buildings were collected for *Legionella* culture during 6 intervals. *Legionella* colonized 60% of the hot water systems before monochloramine versus 4% after conversion. The effectiveness of chloramines for inactivating *Legionella* and biofilm bacteria may be related to its ability to penetrate the biofilm (Kirmeyer et al. 2004a).

5.1.2 Potential Operational and Simultaneous Compliance Issues Associated with Chloramines

Potential issues associated with the use of chloramines include:

- **Nitrification**
- **Increased corrosion and metal release**
- **Taste and odor issues**
- **Weaker disinfectant**
- **Blending issues - chloraminated and chlorinated waters**
- **Safety concerns**
- **Issues with ozonation and GAC filtration**
- **Issues for dialysis patients, fish owners, and industrial customers**

Nitrification

Biological nitrification is the oxidation of ammonia to nitrite and then eventually to nitrate by bacteria and other organisms. Nitrification adversely impacts the effectiveness of chloramines by increasing the chloramine demand, depleting chloramine residuals and thus allowing bacterial regrowth (Kirmeyer et al. 2004a). A loss of disinfectant residual in the distribution system can result in a violation of the SWTR, and may lead to increased vulnerability to contamination. Other adverse effects of nitrification on distribution system water quality include:

- Decrease in dissolved oxygen
- Increase in nitrite and nitrate levels
- Decrease in pH

- Decrease in alkalinity
- Decrease in ORP

Systems that chloraminate can experience nitrification episodes under certain system conditions including but not limited to:

- Excess free ammonia
- Low chloramine residual
- Long water detention times in the distribution system, such as in storage tanks, areas with low demand, and dead ends
- Water temperatures of 25ºC - 30ºC (Wolfe et al. 1988; Wolfe et al. 1990)
- A pH in the range 7.0 to 8.0 is optimum for nitrifying bacteria (Kirmeyer et al. 2004a)

As part of the TCR review process, EPA has published several white papers on issues in the distribution system such as nitrification and biofilm growth. These papers can be found at:
http://www.epa.gov/safewater/disinfection/tcr/pdfs/whitepaper_tcr_nitrification.pdf
http://www.epa.gov/safewater/disinfection/tcr/pdfs/whitepaper_tcr_biofilms.pdf

The AwwaRF report, *Optimizing Chloramine Treatment, Second Edition* (Kirmeyer et al. 2004a) describes the biochemistry of nitrification, its impacts on distribution system water quality, and treatment and control strategies. It also describes relevant utility experiences based on a project survey and case studies.

Recommendations for Addressing this Issue

Nitrification may be controlled by taking certain preventative measures and by implementing corrective actions when monitoring indicates the onset of a nitrification event.

Preventive measure for controlling nitrification were identified in a recent AwwaRF survey by 50 water systems that use chloramination (Kirmeyer et al. 2004a). The most important preventive measures include:

- Distribution system flushing
- Increasing chloramine residual
- Modifying chlorine-to-ammonia nitrogen ratio

Additional preventive methods used by survey respondents include maintaining low concentrations of residual ammonia at the treatment plant effluent, using a source water with the lowest temperature whenever possible, and modifying distribution system hydraulics to minimize water age (e.g. improve water circulation, eliminate dead-ends, open valves, increase turnover rate in storage facilities).

Some systems that chloraminate periodically switch to free chlorine disinfection for a few weeks or months to reduce the population of nitrifying bacteria in the distribution system. However, a recent AwwaRF study (Vikesland et al. 2006) found that "…a periodic switch from a chloramine residual to a free chlorine residual may not be sufficient for long-term control of nitrification within a chloraminated distribution system. Given the higher levels of DBPs observed following a switch to free chlorine, utilities may be better served by careful maintenance of their ammonia feed such that nitrification episodes are minimized."

Monitoring programs specific to nitrification should be developed and implemented. The AwwaRF report, *Guidance Manual for Monitoring Distribution System Water Quality* (Kirmeyer et al. 2002) provides detailed monitoring protocols for nitrification including recommended sampling locations, monitoring parameters, and sampling frequencies. Monitoring protocols are provided for proactive monitoring to establish a baseline database and investigative monitoring in response to a suspected nitrification event. The recommended monitoring parameters for the baseline monitoring program include total chlorine, monochloramine, free ammonia, total ammonia, nitrite, nitrate, HPCs, and water residence time. The investigative monitoring program includes these parameters plus temperature and dissolved oxygen. Monitoring locations may include raw water, point-of-entry to the distribution system, reservoir inlets/outlets, coliform monitoring stations, selected dead-end sites, and low flow sites, depending on the monitoring objective (baseline vs. investigative) and the monitoring parameter.

In combination with monitoring protocols, Kirmeyer et al. (2002) recommend establishing system-specific action levels that will trigger corrective action. For example, Kirmeyer et al. (2004) summarized the nitrification action plan for Irvine Ranch Water District that included three action levels. In Level 1, a nitrite level of 25 to 49 µg/L triggered a review of system operations and additional sampling. In Level 2, an HPC count of 200-500 cfu/mL, a total chlorine residual <0.4 mg/L or a nitrite level of 50 to 74 µg/L triggered additional sampling, additional analyses for nitrate and free ammonia, and reservoir cycling. Level 3 was triggered by an HPC count >500 cfu/mL, a total chlorine residual <0.2 mg/L or a nitrite level ≥75 µg/L, and involved chlorinating and cycling the reservoir, and continued sampling.

Corrective actions that may be implemented when a nitrification event is occurring were also identified in the AwwaRF survey (Kirmeyer et al. 2004a). Pipe flushing was found to be the most effective corrective action. Additional corrective methods identified by survey respondents include:

- Blending low-TOC water which possesses a higher and more stable chloramine residual with nitrifying water (effective in small tanks);
- Combining pipe flushing and monitoring until adequate water quality is re-established; and
- Modifying distribution system hydraulics (eliminate dead-ends).

Increased Corrosion and Metal Release

Nitrification resulting from the use of chloramines can lower the alkalinity and the pH of the water in the distribution system. This can prove detrimental for lead and copper control. Corrosion products and tubercles also interfere with the disinfection of coliform and heterotrophic bacteria, which can lead to increased microbially-induced corrosion.

Changing from free chlorine to chloramines in the distribution system could potentially impact the stability of pipe scales, particularly redox-sensitive minerals such as lead, copper, manganese, and iron. Changes in the solubility and/or permeability of scale materials could possibly result in their desorption and release into the bulk water.

For example, systems with lead service lines could possibly see changes in lead levels as a result of a switch to chloramines. Pipe scale analysis has shown that, in some distribution systems where free chlorine is used, the corrosion by-products on lead service lines contain significant amounts of lead (IV) oxide compounds (Schock 2001; Schock, Wagner and Oliphant 1996; AwwaRF and DVGW-Technologiezentrum Wasser 1996; Lytle and Schock 2005; Schock and Giani 2004; Schock et al. 2005). Lead (IV) oxide scales are highly oxidized and considered to be relatively insoluble in water. If a water system switches from a strong oxidant (chlorine) to a weaker oxidant (chloramines), the ORP necessary to maintain lead (IV) stability may no longer remain. As a result, lead (IV) compounds may be reduced to more soluble lead (II) solids and a subsequent increase in lead concentrations in water may be observed.

The switch to chloramines following historically high levels of chlorine residual (and relatively high oxidation reduction potential as described above), along with the absence of a reevaluation and modification to corrosion control treatment, is the suspected cause of the LCR action level exceedances experienced by Washington, D.C.'s Water and Sewer Authority (DCWASA) beginning in 2002. DCWASA made the conversion from free chorine to chloramines in late 2000 with the goal of reducing TTHM and HAA5 levels in the distribution system. After the conversion to chloramines, elevated lead levels were found in compliance samples from homes with lead service lines. To address the lead corrosion problem, the city accelerated its lead service line replacement program and began orthophosphate treatment in August 2004. The treatment program was successful in reducing elevated lead levels. LCR monitoring results for 2005 and 2006 showed that the calculated 90th percentile values were at or below the lead action level.

There have been some indications that chloramines can corrode brass. Edwards et al. (2004) found accelerated brass corrosion in 7 of 8 brass samples tested, and a slight increase with chloramines as opposed to free chlorine. Reiber et al. (1993) did not observe any additional corrosion of brass in the presence of chloramines above what was seen with free chlorine. Ammonia is known to be corrosive to brass and it is possible that excess ammonia and nitrate, caused by nitrification, can accelerate brass corrosion. Uchida and Okuwaki (1999) found lead corrosion (lead is a component of brass) to be higher in the presence of ammonia and nitrate together. Maas et al. (2005) found that fluoridation of water in combination with chloramines can cause accelerated brass corrosion.

Chloramines have also been found to be corrosive to some elastomer materials. Prolonged exposure of elastomer materials, such as those used in gaskets and valve seals, can lead to cracking and loss of integrity (Reiber 1991). Although free chlorine can also cause corrosion of these materials, chloramines show significantly higher corrosion rates. A recent study of chloramine effects on elastomer materials (Bonds 2004) showed that pipe gaskets made with vulcanized elastomers do not corrode significantly due to their low surface area to volume ratio, even though it was shown that chloramine causes significant corrosion of vulcanized elastomers. Components with higher surface area to volume ratios such as flappers or valve seats may experience more significant deterioration. Both Reiber (1991) and Bonds (2004) found that fluorocarbon elastomers showed the least corrosion of the elastomers tested.

Therefore, using fluorocarbon elastomers in components that will receive high exposure to chloramines will help prevent failure.

Recommendations for Addressing this Issue

Reiber (1993) noted that materials deterioration by monochloramine is less noticeable than by dichloramine. Therefore, maintaining optimal conditions for monochloramine formation may help prevent materials deterioration as well as help control nitrification. Optimal conditions for monochloramine include pH of 8.3, a temperature of 25ºC, and a 4:1 to 5:1 weight ratio of chlorine to ammonia (Kirmeyer et al. 2004a).

Systems can minimize lead corrosion by:

- Optimizing the pH, alkalinity, and DIC of the water; and
- Adding a corrosion inhibitor (i.e., a substance that is phosphate- or silica-based) to the finished water to form a protective coating on the pipes.

Systems concerned with brass corrosion can take steps to limit free ammonia and nitrification as listed in the section on nitrification. The steps listed above will also help mitigate brass corrosion.

To prevent elastomer corrosion, components such as gaskets and flappers should be made of elastomers such as fluorocarbons that have good resistance to chloramines. Education and outreach programs can help customers select the appropriate materials.

Taste and Odor Issues

Chlorine-based disinfectants have some associated taste and odor impacts. Monochloramine has a higher odor threshold and variations in residual concentrations produce less noticeable odors than free chlorine. Dichloramine and trichloramine, however, have much stronger odors than either monochloramine or free chlorine (Krasner and Barrett 1985). Taste and odor problems can also arise from nitrification episodes caused by excess ammonia. Control measures to prevent nitrification are discussed earlier in this section.

Recommendations for Addressing this Issue

To prevent the formation of dichloramine and trichloramine that cause taste and odor problems, the chlorine to ammonia ratio should be carefully controlled and pH should be kept above 7.0. When the chlorine to ammonia ratio exceeds 5:1, dichloramine frequently begins to form. In general, maintaining a ratio between 3:1 and 5:1 should minimize odor problems.

Blending Chloraminated and Chlorinated Water

When water with a chloramine residual is mixed with water with a free chlorine residual, the chlorine to ammonia ratio changes and the resulting changes in distribution system water quality may cause customer complaints and/or possible violations of SDWA regulations. If the additional free chlorine raises the ratio to higher than 5:1, dichloramine and trichloramine can form which have low odor thresholds and can cause customer complaints. If the ratio is raised to 7.6:1 or higher by the additional free chlorine residual, breakpoint reactions can occur. Breakpoint reactions can lead to a total loss of disinfectant residual, which can result in a violation of the SWTR and possibly the TCR if the residual loss lasts long enough for an increase in microbial growth throughout the system. Blending could also cause the water to have excess free chlorine, causing DBP formation and a possible violation of the DBPR.

Recommendations for Addressing this Issue

To avoid breakpoint chlorination, utilities mixing waters with chloramines and free chlorine residuals should determine the residuals in both waters and determine the chlorine to ammonia ratio of the resulting mixture. Some systems have developed computer models to predict these ratios. The models should be calibrated to the specific distribution system in order to be useful. Keeping the chlorine to ammonia ratio below 5:1 in the chloraminated water, which allows an ammonia residual to exist, will allow some addition of water with a chlorine residual before problems occur. A system could also choose to add ammonia again at the point where the waters are mixed to maintain the chlorine to ammonia ratio in the proper range. In either case, the water system also needs to take into account the possibility of excess ammonia causing nitrification. Careful monitoring of excess ammonia, free chlorine, and total chlorine residuals should be carried out to ensure that appropriate ratios are maintained.

Weaker Disinfectant

Monochloramine is a weaker disinfectant than free chlorine as illustrated by the required CT values to achieve inactivation of viruses and *Giardia* cysts (Exhibit 5.1). Both chlorine and monochloramine are ineffective against *Cryptosporidium* oocysts.

Exhibit 5.1 Comparison of Required CT (mg-min/L) values for Inactivation of Viruses and *Giardia* by Free Chlorine and Monochloramine at pH 7 and 10°C

Disinfectant	**2-log inactivation (99%) of viruses**	**4-log inactivation (99.99%) of viruses**	**0.5-log inactivation (68.4%) of *Giardia***	**3.0-log inactivation (99.9%) of *Giardia***
Chlorine	3	6	17[1]	104[1]
Monochloramine	643	1,491	310	1,850

[1] CT values are for free chlorine of <0.4 mg/L

Even at relatively high doses of monochloramine, extremely long residence times are required to achieve required levels of inactivation for viruses and *Giardia* cysts. Systems that switch from free chlorine to monochloramine as their primary disinfectant must benchmark for virus and *Giardia* inactivation.

Recommendations for Addressing this Issue

Systems can compensate for the lower disinfecting power of monochloramine by using a different disinfectant as the primary disinfectant and using monochloramine to maintain a disinfectant residual in the distribution system. Frequently this is done by adding the ammonia some time after the chlorine has been added. This allows a period of time for free chlorine disinfection. While this scheme will result in higher DBPs than using chloramines as the primary disinfectant, it will still result in lower DBP concentrations than when free chlorine is used as both a primary and residual disinfectant. One water system found as little as two minutes of free chlorine contact time prior to ammonia addition achieved desired inactivation results and reduced TTHM by 50 percent over free chlorine alone (Means et al. 1986). Another system used an hour of free chlorine contact time before converting to chloramines without exceeding TTHM regulatory levels (Gianatasio 1985).

Systems with very high TOC may wish to avoid free chlorine altogether. These systems can switch to a different primary disinfectant such as ozone, UV, or chlorine dioxide. See Sections 5.2, 5.3, and 5.4 for more details on these disinfectants, and their advantages and drawbacks.

Safety Concerns

Various safety issues should be considered when switching to chloramines, depending on the type of ammonia used. High concentrations of ammonia can form an explosive mixture of trichloramine when it reacts with chlorine. Ammonia gas is also toxic if released to the atmosphere in sufficient concentrations. Ammonium sulfate does not have as many safety issues as either anhydrous ammonia or aqueous ammonia, but it is considerably more expensive and should be kept dry to avoid feed problems.

Recommendations for Addressing this Issue

To avoid the possibility of an explosive reaction between bulk chlorine and bulk ammonia, the two chemicals should be stored in separate rooms. Feed points and pipes for chlorine and ammonia should also be placed at least five feet apart (USEPA 1999b).

To avoid the release of ammonia into the atmosphere, several precautions should be taken. Anhydrous ammonia should be stored in pressurized containers away from temperature extremes (temperatures greater than 125°F will cause pressure buildups in the tank). Aqueous ammonia tanks should be vented to keep pressure from building up from ammonia volatilization. Keeping the temperature low will also help to prevent volatilization, which can cause vapor lock in pumps. Buildings where ammonia is stored should be well-ventilated and should include storage areas for respirators just outside the ammonia storage area. If large amounts of ammonia are stored, an emergency scrubber should also be installed. Additional safety precautions are detailed in the report, *Optimizing Chloramine Treatment, 2nd ed*. (Kirmeyer et al. 2004a).

Issues with Ozonation and GAC Filtration

Wilczak et al. (2003) found that ozone use prior to chloramination increases the assimilable organic carbon concentration and could destabilize the chloramine residual, leading to problems with chloramine residual concentrations at the ends of the distribution system.

Adding chloramines before a GAC filter may lead to nitrification in the GAC filter. It has been found that a reaction between chloramines and GAC may free up ammonia and encourage the growth of ammonia oxidizing bacteria in the GAC filters (Tokuno 1999).

Recommendations for Addressing this Issue

Installing a GAC filter after ozone to remove AOC, then allowing a few minutes of free chlorine contact time to oxidize any remaining organics before ammonia is added can be a more reliable way to allow the formation of a stable chloramine residual. Chloramines should not be added prior to GAC filters.

Issues for Dialysis Patients, Fish Owners, and Other Customers

Chloramines can be toxic to dialysis patients and must be removed before water is used in dialysis machines. Chloramines are also toxic to fish and therefore must be removed from the water before it is used for pet fish or before water is discharged to natural fish habitats. The removal of chloramines from tap water is more difficult to achieve, and more costly, than free chlorine. This also impacts water customers who produce foods, beverages, and pharmaceuticals.

Recommendations for Addressing this Issue

Because the process for removing chloramines is different from that for removing chlorine, dialysis patients and fish owners should be notified in advance of the switch to chloramines. Water systems may also want to consider adding special notification language for fish owners and dialysis patients in their consumer confidence reports, so that the information is provided on an annual basis. Information on how other systems conducted community outreach before, during, and after treatment with chloramines are presented in the AwwaRF document, *Optimizing Chloramine Treatment, Second Edition* (Kirmeyer et al. 2004a).

5.1.3 Recommendations for Gathering More Information

Read Case Studies

Three case studies in Appendix B address simultaneous compliance issues for systems that switched to chloramines as part of an effort to reduce DBP concentrations:

- ***Case Study #9 - Modifying Chloramination Practices to Address Nitrification Issues*** on page B-51 describes a surface water system serving 115,000 people that took steps to control nitrification in the distribution system after switching to chloramines;

- ***Case Study #13 - Chlorine Dioxide for Primary Disinfection and Chloramines for Secondary Disinfection*** on page B-75 describes a surface water treatment plant in a wholesale system serving seven municipalities and approximately 92,000 people. The treatment plant switched from chlorine to chlorine dioxide as its primary disinfectant and from chlorine to chloramines for residual disinfection. In addition, the system uses chlorine dioxide intermittently as a pre-oxidant in its raw water. Among the challenges the system has encountered is being able to achieve sufficient *Cryptosporidium* inactivation to be granted LT2ESWTR credit and still comply with the Stage 1 DBPR's chlorite MRDL; and

- ***Case Study #14 - Chlorine Dioxide for Primary Disinfection and Chloramines for Secondary Disinfection*** on page B-81 describes a small surface water system that achieves its required CT with chlorine dioxide and maintains its disinfectant residual in the distribution system with chloramines.

See Additional References

Readers can find more references on this topic listed in the following sections of Chapter 7:

- Section 7.1.1 includes general references on water treatment
- Section 7.1.2 includes references on controlling DBP formation
- Section 7.1.3 includes several references on corrosion/disinfection interrelationships
- Section 7.1.5 includes references on using distribution system BMPs to control water quality in the distribution system.
- Section 7.1.12 includes additional references on chloramines.

Of particular note, the new publication *Fundamentals and Control of Nitrification in Chloraminated Distribution Systems (M56)*, published by AWWA in 2006, provides background information on the occurrence and microbiology of nitrification and offers current and practical approaches to nitrification prevention and response.

Consider Additional Monitoring

Additional monitoring may benefit water systems using chloramines to address and prevent potential simultaneous compliance issues. Specific guidelines on monitoring to detect potential nitrification events is discussed previously in Section 5.1.2.

Consider Other Tools

Additional tools listed in Chapter 6 may help systems evaluate and improve their current water system in relation to the compliance issues they may face when modifying their treatment operations. Readers are encouraged to read through Chapter 6 before making any final compliance decisions. The following AwwaRF reports provide additional information:

- *Optimizing Chloramine Treatment, Second Edition* (Kirmeyer et al. 2004a) describes chloramine chemistry, the advantages and disadvantages of chloramination, an approach for evaluating conversion to chloramines, and design and implementation issues for chloramine feed systems. It also describes relevant utility experiences based on a project survey and case studies.

- *Internal Corrosion of Water Distribution System* (AwwaRF and DVGW-Technologiezentrum Wasser 1996) provides bench-scale and pilot testing protocols that can be used to evaluate changes in corrosion potential due to the switch to chloramines.

- *Optimizing Corrosion Control in Water Distribution System* (Duranceau, Townley, and Bell 2004) provides techniques for instantaneous corrosion monitoring.

- *Tools and Methods to Effectively Measure Customer Perceptions* (Colbourne 2001) describes tools that allow utilities to measure customer perceptions and changes in their opinions toward the use of chloramines.

- *Water/Wastewater Costs, Windows Version 3.0, (Wesner 2000)* provides capital and O&M cost calculations for various water treatment processes based on user inputted design parameters.

5.2 Ozonation

Ozone is a powerful chemical disinfectant and an alternative to free chlorine. It is an unstable gas that is generated on-site, using either air or liquid oxygen. It is very effective at disinfecting many microbes and as a pre-oxidant. It can, however, convert bromide to bromate, a DBP regulated by the Stage 1 D/DBPR. It also oxidizes organic matter into smaller molecules, which can provide a more easily degradable food source for microorganisms in the distribution system. Because of its instability in water, ozone cannot be used to provide a disinfectant residual in the distribution system. Furthermore, ozone can produce odor compounds such as aldehydes and ketones.

5.2.1 Advantages of Ozonation

The main advantages of ozone are:

- **Effective against pathogens**
- **Does not form chlorinated DBPs**
- **Effective pre-oxidant**
- **Can oxidize taste and odor compounds**
- **Can raise UV transmittance of water and UV disinfection effectiveness**
- **Independent of pH**
- **Can aid coagulation**

Effective Against Many Microbes

Ozone is a highly effective disinfectant because of its high oxidation potential. It is the strongest of all the commonly used chemical disinfectants. It is most effective against viruses and slightly less effective against *Cryptosporidium* oocysts. As with most chemical disinfectants, the degree of microbial inactivation is temperature dependent. Inactivation is greater at higher temperatures.

Exhibit 5.2 shows the required CT values at 10°C for inactivation of various microbes for each of the commonly used chemical disinfectants. Comparing the CT values shows the relative effectiveness of the disinfectants.

Exhibit 5.2 Required CT values (mg-min/L) for Chemical Disinfectants at 10°C

Disinfectant	**4-log Inactivation (99.99%) of Viruses**	**3-log Inactivation (99.9%) of *Giardia***	**1-log Inactivation (99.9%) of *Cryptosporidium***
Ozone	1	1.43	9.9
Chlorine[1]	6	104	N/A
Chlorine Dioxide	4.2	23	277

Source: USEPA 2003a
N/A - these disinfectants are ineffective against *Cryptosporidium*
[1] at pH = 7.0 and chlorine residual = 0.4 mg/L

The exhibit shows that ***ozone*** is the most effective disinfectant against ***all three microbes listed.*** In addition to satisfying microbial disinfection requirements, ozone can aid in compliance with the Stage 2 DBPR by eliminating chlorine as a primary disinfectant and lowering the required dose of secondary disinfectant. Systems with DBP concentrations above a certain threshold that switch to ozone from another primary disinfectant are required by the IESWTR, LT1ESWTR, and LT2ESWTR to benchmark for *Giardia*, *Cryptosporidium*, and viruses. More details on disinfection profiling and benchmarking can be found in the *Disinfection Profiling and Benchmarking Guidance Manual* (USEPA 1999a).

Does Not Form Chlorinated DBPs

Ozone by itself does not form chlorinated DBPs. Therefore, using ozone instead of chlorine for primary disinfection can lower DBP formation and aid in compliance with the Stage 2 DBPR. Ozone can react with bromide, however, to form bromate, which is a non-chlorinated DBP with an MCL of 10 ppb set under the Stage 1 D/DBPR (see section 5.2.2 of discussion of bromate formation).

Effective Pre-oxidant

Ozone's high oxidation potential also means it acts well as a pre-oxidant. It can be used to oxidize iron and manganese so they can be removed through coagulation and sedimentation. Ozone can oxidize arsenic (III) to arsenic (V) which enhances its removal. Many organic compounds are oxidized by ozone as well. If the dose is high enough, ozone can even completely mineralize some organics, lowering the concentration of DBP precursors and aiding in Stage 2 DBPR compliance.

Can Oxidize Taste and Odor Compounds

Ozone is especially useful in oxidizing taste and odor compounds such as geosmin and 2 -methylisoborneol (MIB). The efficiency of ozone at degrading geosmin and MIB is further increased if hydrogen peroxide is added in addition to the ozone, a process referred to as peroxone.

Raises UV Transmittance of Water

Low UV transmittance (UVT) of the water will result in less efficient UV disinfection. Ozone treatment before UV can oxidize those compounds that absorb UV, thereby increasing transmittance and UV's disinfection effectiveness. Although it may be cost-prohibitive to install both UV and ozone, a system with one of the two technologies in place may benefit from installation of the other. This arrangement would require either chlorine or chloramines to maintain a distribution system residual.

Independent of pH

The disinfection efficiency of ozone, unlike chlorine, does not depend on pH for the range of pH values normally encountered in water treatment. This enables plants to adjust pH to optimize coagulation, prevent corrosion, or alter DBP formation reactions without losing disinfection capability. It also removes some of the seasonal variability that is usually found in disinfection benchmarks. Note, however, that bromate formation is impacted by the pH of the water. This is discussed in more detail in Section 5.2.2.

Can Aid Coagulation

Some systems have reported improvements in coagulation when they added ozone prior to coagulation (Reckhow et al. 1993, Stolarik and Christie 1997). Other systems have found no change or even increases in filtered water turbidity after ozonation. The interaction between ozonation and coagulation is complex and entails the interaction of many parameters. Therefore, results will vary significantly from plant to plant. Systems should conduct bench-scale and preferably pilot-scale tests to determine how ozone will affect the systems water quality. Note that adding ozone after coagulation and sedimentation may have the advantage of lowering ozone demand allowing the same CT with a lower ozone dose.

5.2.2 Potential Operational and Simultaneous Compliance Issues Associated with Ozonation

The main operational and simultaneous compliance issues associated with ozone are:

- **May form bromate**
- **Forms smaller organic compounds**
- **Does not provide a residual in the distribution system**
- **May increase dissolved oxygen in the water**
- **Can form taste and odor compounds**

- **Can increase corrosion**
- **Ozone bubbles can hinder filter performance**
- **Switching to ozone with biological filtration may cause manganese release from filters**
- **Requires additional training**

This section summarizes these issues and provides recommendations for some ways to address them.

May Form Bromate

If bromide is present in the source water, it can react with ozone to form bromate. In the presence of organic matter, ozone can also form brominated THMs and HAAs. The Stage 1 D/DBPR requires compliance with a 10 µg/L MCL for bromate. Therefore, systems considering installing ozone should evaluate whether compliance with the bromate MCL may be an issue.

Whether bromate or brominated organic DBPs form depends on the pH and organic content of the water. Lower pH water and high DOC concentrations tend to favor the formation of brominated organic compounds. Systems using ozone may be able to reduce their chlorine dose, however, and as a result improve compliance with TTHM and HAA5 MCLs. Higher pH and low dissolved organic concentration generally lead to greater bromate formation.

Recommendations for Addressing this Issue

There are several techniques that public water systems can use to control disinfection byproduct formation when bromide ion is present. These include:

- Optimizing the pH
- Keeping the ratio of ozone to DOC low
- Adding ammonia

Lowering the pH favors formation of brominated organic compounds over bromate. Performing ozonation at a pH below 7 will lower the formation of bromate. This is a particularly good option for systems that have low DOC concentrations and do not have problems with high TTHM or HAA5 concentrations in their finished water. If DOC concentrations are high, however, this method of bromate control may result in exceeding HAA5 or TTHM MCLs. Systems also need to consider other effects of lowering pH such as increased corrosion, impacts on the effectiveness of secondary disinfectants, and impacts on coagulation. (See Section 3.4 for a more complete discussion of the effects of changing pH.)

If the ratio of ozone to DOC is kept low, the formation of bromate and brominated organic compounds can be reduced. This can be done by either lowering the ozone dose or by lowering DOC concentrations. Lowering the ozone dose would mean increasing the contact time, unless the system currently achieves more than the required CT. The ability to extend the contact time will depend on the ozone demand and decay of the water as well as operational limitations. Determining the ozone demand and decay rate of a given water before ozone is installed will help determine the possibilities of this option. DOC can be lowered by removing it prior to the ozone addition. If a system does not need to use ozone for pre-oxidation, it may want to add the ozone after sedimentation, or even after filtration, to achieve a lower ozone to DOC ratio. It is not typical, however, to ozonate after filtration, because of higher AOC concentrations being introduced into the distribution system and the related problems of TCR compliance and nitrification that may occur. If a system needs to pre-oxidize, a small dose of ozone can be added to the raw water and a higher dose can be added after sedimentation or filtration. Using biological filtration in this case can be especially effective for lowering DBPs, since biological filtration tends to remove aldehydes and other small organic compounds that can make up a large fraction of the DOC after ozonation.

Adding ammonia to water containing bromide and ozone will lead to bromamine formation. Bromamines react more slowly with organic matter and form fewer brominated organic compounds and less bromate. Ammonia addition, however, can lead to nitrification problems in the distribution system. See Section 5.1 for more details on controlling nitrification when ammonia is added.

Systems with high bromide concentrations, especially those with high DOC as well, may not be able to use ozone even if they adopt these mitigation methods. Systems that use ozone to inactivate *Cryptosporidium* may have an especially hard time, in this regard, because *Cryptosporidium* requires a much higher ozone dose. Since the LT2ESWTR does not grant disinfection credit for an ozone residual in the first contact chamber, many systems will want to increase their ozone dose to help them gain CT in subsequent chambers. Bromide can be removed by the use of anion exchange, but this is generally not a cost-effective solution.

Forms Smaller Organic Compounds

Ozone breaks down organic compounds into smaller chain organic molecules, especially aldehydes and ketones. These smaller organic molecules often measured as “assimilable organic carbon” (AOC) are more readily biodegradable and can increase biological growth downstream of the ozone addition point. AOC is a measure of the organic carbon readily available as food for microorganisms. Some systems that have added ozone without biological filtration have experienced increased AOC and microbial growth in the distribution system (Van der Kooij 1997). Increased biological growth in the distribution system can lead to higher disinfectant demand and potentially TCR violations. Biological growth can also cause increased corrosion, possibly leading to violations of the Lead and Copper Rule (LCR) as well as to taste and odor problems.

Recommendations for Addressing this Issue

An effective way to remove smaller organic compounds is biological filtration.

An effective way to reduce AOC is biological filtration. Biological filtration can be achieved by not having a disinfectant residual in the water entering the post-ozone filter. The increased dissolved oxygen that results from the ozonation, combined with the high surface area per volume of the filter media, provide conditions for biological growth to occur on the filters. The biological growth on the filters then consumes the AOC, using it as a food source. Biological filtration has been shown to lower AOC effectively, even when very short residence times are used. Longer residence times can lead to the reduction of other organic compounds as well (LeChevallier et al. 1992). See Urfer et al. (1997) for more details on biological filtration.

Any type of filter media can accommodate biological filtration. Slow sand filters, rapid rate dual media filters, and GAC filters have all been successfully used for biological filtration. Rapid rate filters have been shown to remove AOC, though they may not remove all of the biodegrable dissolved organic carbon (BDOC), which is a portion of organic matter that can still be used by microbes as a food source but takes longer for the microbes to metabolize than AOC. Slow sand filters and GAC contactors have been shown to remove both BDOC and AOC. GAC has the added benefit that it will adsorb or concentrate organics, thus extending the time available for the microbes to metabolize the organic matter.

Switching to biofiltration can present its own challenges. Although biofilters remove turbidity as well as other filters, they have shown higher particle counts than traditional filters. They have also shown increased headloss over traditional filters. Systems switching to biofiltration may want to consult the AwwaRF report "Optimizing Filtration in Biological Filters" (Huck et al. 2000) to design the best biofiltration system.

Does Not Provide a Disinfectant Residual in the Distribution System

Ozone reacts very quickly and therefore is not able to provide a residual for use in the distribution system. A secondary disinfectant is, therefore, required to maintain a disinfectant residual in the distribution system as required by the SWTR.

Recommendations for Addressing this Issue

Chlorine can often be used as an effective residual disinfectant after ozonation. Since ozone is used to achieve primary disinfection, lower doses of chlorine can be used as a secondary disinfectant, resulting in lower DBP levels. Ozone followed by biological filtration reduces DBP precursors, which also leads to lower DBP levels. If biological filtration is not used, the system should be careful that the additional smaller organic molecules do not react with chlorine added as a secondary disinfectant to produce higher DBP concentration than if chlorine alone were added. Chloroform has been found to be higher in some systems which used ozone without biological filtration than it was before ozone was implemented.

Chloramines can also be used to provide a distribution system residual after ozonation. Chloramines will result in lower DBPs than chlorine. As mentioned above, adding ammonia with the ozone will provide benefits regarding the formation of brominated DBPs. If this approach is taken, chlorine can be added after filtration to form the chloramines. For a full discussion on the benefits and drawbacks of chloramines as a secondary disinfectant, see Section 5.1.

May Introduce Dissolved Oxygen into the Water

When ozone reacts in water it forms dissolved oxygen. This oxygen may remain dissolved in the water. Dissolved oxygen can increase corrosion of metals. It can also cause increased growth of aerobic bacteria and problems with TCR compliance.

Recommendations for Addressing this Issue

Corrosion-resistant materials should be used in the ozone feed equipment, the contact chamber, and any other plant equipment that comes into contact with the water after ozonation and before the dissolved oxygen is dissipated. The best way to prevent dissolved oxygen from entering the distribution system is to run the filters in biologically active mode. This will lower the dissolved oxygen, as well as remove AOC.

Systems using ozone after filtration and unfiltered systems may need to take steps to control microbial growth in the distribution system. Control measures include ensuring a sufficient residual throughout the system, looping dead ends in the distribution system, and minimizing retention time in reservoirs. Systems may also want to raise the pH of the water or add a corrosion inhibitor to prevent corrosion.

Can Form Taste and Odor Compounds

Ozone is generally very effective in destroying taste and odors compounds, but in some cases ozonation of organic matter forms aldehydes and other compounds that can impart tastes and odors to water.

Recommendations for Addressing this Issue

Systems should consider using a GAC filter or biologically active filtration to help eliminate aldehydes formed during ozonation, before the water reaches customers.

Increases Corrosion

Ozone is corrosive and can corrode steel pipes and fittings, concrete, rubber gaskets, and other material with which it comes into contact in the treatment plant.

Recommendations for Addressing this Issue

All material that comes into contact with ozone residual should be resistant to ozone. This includes any equipment which might be exposed to off-gassed ozone. Equipment manufacturers should be contacted to ensure compatibility of their equipment with ozone.

Ozone Bubbles Can Hinder Filter Performance

Ozone can de-gas in the filter and bind to the filter media. This can adversely affect filter performance and reduce the effectiveness of filter backwashing.

Recommendations for Addressing this Issue

If ozone is injected under pressure, it should be de-gassed before the filters.

Switching to ozone and biological filtration may cause release of manganese from filters

Iron-based coagulants often contain significant amounts of manganese as an impurity in the coagulant. When systems that use iron coagulants also pre-chlorinate, a layer of oxidized manganese can form on the filter media surface. If the system switches to ozone and stops pre-chlorinating to achieve biological filtration, this manganese has been found to reduce and be released into the filtrate water (Wert et al. 2005, Gabelich et al. 2005). Therefore systems which are using or have historically used iron coagulants and switch from chlorine to ozone before the filter in order to take advantage of biofiltration may experience elevated manganese levels. In some cases these levels of manganese have violated secondary standards for manganese (Gabelich et al. 2005).

Recommendations for addressing this issue

Wert et al. (2005) found that the release of manganese from filters was much more at rapid at pH 6 than at pH 8. Therefore, maintaining a pH near 8 going through the filter may prevent elevated manganese levels. Switching to a coagulant with lower manganese impurity concentrations will help future manganese releases but will not solve any already accumulated manganese problems. One system found that they were able to clean the manganese from anthracite media using a two step process involving acid and hydrogen peroxide (Gabelich et al. 2005). This process, however, did not remove manganese from sand media. Another option is to replace the filter media.

Requires Additional Training

Ozone disinfection is an advanced technology and requires different procedures and equipment compared to conventional technologies. There are also safety issues, such as containment and destruction of ozone off-gas.

Recommendations for Addressing this Issue

Additional training will be needed to ensure that operators can use equipment correctly. They will need to become familiar with additional chemicals used for ozone quench. Operators should also be aware of safety concerns related to off-gassing and destruct units.

5.2.3 Recommendations for Gathering More Information

Read Case Studies

Two case studies in Appendix B describe simultaneous compliance challenges faced by utilities using ozone.

Case Study #10 - Ozonation on page B-57 describes a surface water system serving approximately 115,000 people that installed ozone to control both *Cryptosporidium* and disinfection byproducts. The system was concerned about how ozone might result in increased AOC in its finished water, so biofiltration was also installed to address potential problems that could have arisen in the distribution system as a result.

Case Study #11 – Ozonation and Biological Filtration on page B-65 describes a system that significantly expanded its capacity at the same time that it installed ozone. Its source is a river with high TOC, so this system was also concerned with ozone's impact on AOC levels in the finished water. Four new biological filters were installed and 12 existing filters were converted to biological filtration.

See Additional References

Readers can turn to Chapter 7 for more references on this topic. Section 7.1.1 includes general references on water treatment, Section 7.1.2 includes references on controlling DBP formation, and Section 7.1.13 includes references on Ozone.

Consider Additional Monitoring

The following are some suggestions for additional monitoring that may benefit water systems using ozone. The purpose of these monitoring suggestions is specifically to address and prevent potential simultaneous compliance issues. Water system managers should discuss process control monitoring with the manufacturer of their ozonation units or their engineer.

- ✓ Dissolved organic carbon (DOC) measurements in water being ozonated, and calculation of the ozone:DOC ratio. By keeping the ozone:DOC ratio low, formation of bromate and brominated organic compounds can be reduced;

- ✓ AOC and/or BDOC monitoring after biological filtration to verify that they are being removed reliably;

- ✓ If there is no biological filtration treatment step, AOC and/or BDOC monitoring of finished water before it enters the distribution system to track whether levels are high enough to cause problems with biofilm growth;

- ✓ HPC measurements at locations throughout the distribution system and in plant effluent, to watch for increased biofilm growth;

- ✓ Dissolved oxygen at points after ozonation in the treatment plant, as part of an effort to control levels and limit corrosion in the plant;

- ✓ Dissolved oxygen at entry points to the distribution system to make sure it has been reduced to acceptable levels and will not induce distribution system corrosion;

- ✓ Taste and odor in finished water since ozonation can create off-odors; and

- ✓ Ozone residual in the contactor to ensure proper CT, and after the contactor to ensure proper removal and safety.

Consider Other Tools

In addition to water quality monitoring, there are additional tools available in Chapter 6 to help systems evaluate and improve their current water system in relation to the compliance issues they may face when modifying their treatment operations. Examples of tools that can be used when ozone is used for Stage 2 DBPR compliance include:

- The "Guidance Manual for Monitoring Distribution System Water Quality" (Kirmeyer et al. 2002) which can be used to assist water utilities in implementing a distribution system water quality data collection and analysis program;

- The AwwaRF report "Internal Corrosion of Water Distribution System" (AwwaRF and DVGW-Technologiezentrum Wasser 1996) which provides bench-scale and pilot testing protocols that can be used to evaluate changes in corrosion potential due to the switch to ozonation;

- The AwwaRF report "Optimizing Corrosion Control in Water Distribution System" (Duranceau, Townley, and Bell 2004) which provides techniques for instantaneous corrosion monitoring;

- EPA's Environmental Technology Verification Program collects performance data on many environmental technologies, including ozone. Reports for each technology can be found on the website at: http://www.epa.gov/etv/verifications/verification-index.html;

- *Water/Wastewater Costs, Windows Version 3.0, (Wesner 2000)* which provides capital and O&M cost calculations for various water treatment processes based on user inputted design parameters.

- The AwwaRF report "Water Utility Self-Assessment for the Management of Aesthetic Issues" (McGuire et al. 2004) which can be used to guide utilities in conducting self-assessment of taste and odor issues caused by ozonation and to identify subsequent control strategies;

- The AwwaRF report "Tools and Methods to Effectively Measure Customer Perceptions" (Colbourne 2001) which describes tools that allow utilities to measure customer perceptions and changes in their opinions toward the use of ozonation;

- The AwwaRF report "Ozone-Enhanced Biofiltration for Geosmin and MIB Removal" (Westerhoff et al. 2005) which describes the removal of taste and odor compounds through the use of biological filtration; and

- EPA's *Microbial Toolbox Guidance Manual* (USEPA N.d.e) which describes technologies which can be used for compliance with the LT2ESWTR. The manual describes advantages and disadvantages for each technology and lists design and operating considerations.

Readers are encouraged to read through Chapter 6 before making any final compliance decisions.

5.3 Ultraviolet Light (UV)

Recent research indicating that UV light can inactivate *Cryptosporidium* at relatively low lamp intensities has spurred interest in its use for drinking water disinfection. UV light works by damaging the genetic material of microorganisms, interfering with the ability of pathogens to replicate and therefore with their ability to be infective. Similar to chemical disinfectants, the extent of UV inactivation depends on the intensity of the light and the time the microorganism is exposed to it. UV is an effective way to disinfect without producing regulated DBPs. UV does not provide a residual, however, so it is not effective in providing a distribution system residual. Extensive information on the mechanisms of UV disinfection and recommendations on UV system design, validation, and operation are provided in the UV Disinfection Guidance Manual (USEPA 2006b).

If UV is being used as a toolbox option to comply with LT2ESWTR, UV reactors must be validated according to state guidelines and operate within the validated parameters. For purposes of design and operation, EPA recommends that systems strive to deliver the required UV dose at all times during treatment (USEPA 2006b).

5.3.1 Advantages of UV

Advantages

UV light's advantages include:

- **It can inactivate chlorine-resistant pathogens such as *Cryptosporidium* oocysts and *Giardia* cysts at relatively low doses;**
- **It does not produce regulated DBPs; and**
- **Its effectiveness is not pH or temperature dependent.**

Inactivates Cryptosporidium and Giardia

UV disinfection gained attention in the U.S. drinking water market when it was shown that it could inactivate *Cryptosporidium* oocysts and *Giardia* cysts. This gives UV an advantage over chlorine or chloramines, which are ineffective against *Cryptosporidium*. If properly tested and validated, UV is one of the least expensive options for systems that are required to achieve additional *Cryptosporidium* inactivation under the LT2ESWTR (USEPA 2006b). UV can also meet SWTR requirements for *Giardia* inactivation.

Does Not Produce Regulated DBPs

UV disinfection, as a photochemical process, does not produce any of the regulated byproducts that chemical disinfectants such as chlorine, ozone, and chlorine dioxide produce. Surface water systems and systems using GWUDI of surface water may meet Stage 2 DBPR requirements by switching to UV disinfection and lowering their doses of chemical disinfectants.

Systems making this change will be required to benchmark their disinfection process under LT2ESWTR requirements before making the change. See Section 5.3.2 for further discussion of UV benchmarking requirements. Systems will also need to continue to meet the residual disinfection requirements of the SWTR.

Not pH or Temperature Dependent

Research has shown that temperature effects on UV dose-response are minimal (USEPA 2006b). Dose response is also independent of pH in the range of 6 to 9 (Malley 2000). This gives systems more flexibility to adjust pH to control coagulation, or to lower production of DBPs without also affecting disinfection efficiency. This could also mean simpler operations if the UV dose does not need to be adjusted seasonally (although dose could vary seasonally if the levels of UV absorbing compounds in the water being treated vary seasonally).

5.3.2 Potential Operational and Simultaneous Compliance Issues Associated with UV Disinfection

Potential operational and simultaneous compliance issues associated with UV disinfection include:

- **Substances in water can interfere with UV disinfection**
- **Hydraulic upsets can lower the delivered dose and possibly cause lamp breakage**
- **Much higher doses are needed for virus inactivation**
- **UV disinfection provides no distribution system residual**
- **Power quality problems can disrupt disinfection**
- **Requires additional training**

This section provides brief descriptions of these issues and suggestions for addressing them.

Substances in Water Can Interfere with UV Disinfection

Because UV disinfection relies on UV light interacting with the organism's genetic material to be effective, any substance that either absorbs or refracts the germicidal UV light can interfere with disinfection. A common measure of the fraction of germicidal light (i.e., light specifically with a wavelength of 254 nanometers) transmitted through a material is UV Transmittance (UVT). The higher the UVT, the better UV light can be transmitted through the water and the more effective the treatment. Compounds in source waters that can absorb or refract UV light and reduce UVT include humic and fulvic acids, phenols, metals (e.g., iron and manganese), and anions (e.g., nitrates) (USEPA 2006b). The LT2ESWTR requires water systems to account for UV absorbance of the water during validation testing.

In addition to absorbing UV light and decreasing UVT, compounds in the water can foul the external surfaces of the lamp sleeves. The rate of fouling depends on water quality characteristics such as hardness, alkalinity, ion concentration, and pH.

The presence of disinfectants upstream of UV treatment can impact UV performance. Ozone is a strong absorber of UV light and can interfere with disinfection if not quenched prior to UV treatment. Ozone treatment, however, can be effective in increasing the UVT. Some chlorine residual can be lost if water with a free or total chlorine residual is passed through a UV reactor (USEPA 2006b).

Recommendations for Addressing this Issue

Systems should carefully evaluate their water quality during the planning phase for their new UV facility. UVT is the most important water quality characteristic affecting UV facility design (USEPA 2006b); therefore, care should be taken to characterize UVT during typical operations as well as during storm events, seasonal changes, reservoir turnover, and source water blends. UV absorbance of the water (i.e., UVT) must be accounted for during validation testing.

EPA recommends that systems determine a “fouling factor” during the planning phase to account for lower UVT caused by fouling of the lamp sleeves (USEPA 2006b). This factor is defined as the estimated fraction of UV light passing through a fouled sleeve compared to a new sleeve. UV reactors typically allow for cleaning of lamp sleeves to remove deposited material. Three common approaches are off-line chemical cleaning, on-line mechanical cleaning, and on-line mechanical-chemical cleaning. More frequent lamp cleaning can increase the fouling factor. Lamp fouling should be accounted for during validation testing.

Systems can modify their treatment to increase UVT and reduce the potential for fouling of lamp sleeves. Pre-oxidation and enhanced coagulation are potential treatments that can be used for this purpose. Their usefulness should be evaluated on a case-by-case basis.

Ozone, if used for taste and odor control, will generally be added before the filters and will not enter the UV reactor. If this is not the case and an ozone residual is present in the water before it enters the UV unit, the ozone should be quenched. Ozone can be quenched by air stripping in the last chamber of the ozone contactor, or by using a reducing agent such as hydrogen peroxide. Some studies suggest, however, that ozone quenching using hydrogen peroxide can be slow in low-alkalinity water (National Research Council 2000). The ozone residual should not be quenched with thiosulfate, as thiosulfate also absorbs UV.

If chlorine dioxide is being used, it should be added after the UV reactor. See Section 5.4 for further details on chlorine dioxide use. If corrosion inhibitors that contain UV-absorbing compounds are used, they should be added after water has passed through the UV reactor.

Lamp Breakage

Lamp breaks can be caused by debris in water, temperature variations, water hammer, electrical surges, or improper installation (USEPA 2006b). Lamps in most UV reactors contain mercury or an amalgam of mercury and another compound such as gallium or indium. If lamps break during reactor operations, there is a risk of exposure to mercury.

Recommendations for Addressing this Issue

Very few incidents of on-line lamp breaks have been documented. Appendix E of the *Ultraviolet Disinfection Guidance Manual* (USEPA 2006b) provides design and operating recommendations to minimize the occurrence of breaks and to develop written procedures to be followed if a break does occur. To isolate the mercury, systems can install spring-return actuated valves with a short closure time on the reactor inlet and outlet piping. Systems should also consider installing a strainer or mercury trap. EPA recommends that systems evaluate the applicability of various isolation techniques on a case-by-case basis.

Virus Inactivation

While UV disinfection is highly effective against protozoa such as *Cryptosporidium*, it is less effective against viruses. The LT2ESWTR requires systems considering substituting current chlorination with UV disinfection to benchmark with respect to viruses, *Giardia,* and *Cryptosporidium* and consult with the state to be sure that sufficient inactivation is maintained.

While UV disinfection is highly effective against protozoa such as *Cryptosporidium* oocysts, it is less effective against viruses.

Exhibit 5.3 shows the ratio of CT required for inactivation of viruses and the CT required for the inactivation of *Cryptosporidium* for chlorine dioxide and ozone. This ratio can be compared to the ratio of UV dose required for inactivation of viruses and the UV dose required for the inactivation of *Cryptosporidium*. This ratio is much lower for chlorine dioxide and ozone compared to UV, meaning that chlorine dioxide and ozone are more effective for inactivation of viruses compared to *Cryptosporidium*, while UV is the opposite.

Exhibit 5.3 Ratio of CT values for Inactivation of Viruses and *Cryptosporidium* at 10^{o}C

Disinfectant	**Ratio of Virus Inactivation to Cryptosporidium Inactivation**	
	Ratio of 2-log virus inactivation (99.0%) CT to 0.5-log Cryptosporidium inactivation CT (68.4%)	Ratio of 4-log virus inactivation CT (99.99%) to 3.0-log Cryptosporidium inactivation CT (99.9%)
Chlorine dioxide	0.03	0.03
Ozone	0.10	0.03
UV[1]	17.2	15.5

[1] UV doses are in mJ/cm^2 and are calculated using safety factors based on the use of low pressure mercury lamps. They may vary depending on the reactor validation method. See the *Ultraviolet Disinfection Guidance Manual* (USEPA 2006b) for details.

Recommendations for Addressing this Issue

Systems that adopt UV disinfection will need to take special care to ensure that the virus benchmark is achieved. The state should be consulted throughout the planning process to ensure that inactivation requirements can be met to achieve the necessary credit.

To receive credit for disinfection with UV light, the LT2ESWTR requires water systems 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. At the time of this publication, EPA is not aware of an available challenge microorganism that allows for full-scale testing of UV reactors to demonstrate 4-log inactivation of viruses at a required dose of 186 mJ/cm^2. Methodologies for challenge testing at doses necessary to inactivate UV resistant viruses may be developed in the future.

Until then, UV technology should be used in a series configuration or in combination with other inactivation or removal technologies to provide a total 4-log treatment of viruses. The second option uses a different treatment to achieve virus inactivation and uses UV only for *Cryptosporidium* and *Giardia* inactivation. If a chemical disinfectant is used, it could be added after the UV reactor to maintain a residual in the distribution system or it could be added prior to the UV reactor where it could also serve as a preoxidant. Surface water systems will need to add secondary disinfection to comply with the entry point and distribution system residual requirements of the SWTR. If a second disinfectant is used also for additional virus inactivation, it must achieve the required inactivation before the first customer. Chlorine will provide virus inactivation with a relatively low dose, but may produce DBPs and could create problems with Stage 2 DBPR requirements. Chloramines will have less DBP formation but will require significantly longer contact time in the clearwell to ensure appropriate inactivation before the first customer. See Section 5.1 for more details on the use of chloramines.

If pre-oxidation is practiced, chlorine, ozone, or chlorine dioxide can be used. Chlorine may not be an attractive solution because the production of DBPs. Ozone will likely be cost prohibitive unless it is already installed; in which case it would have numerous advantages.

UV Does Not Provide a Residual

UV disinfection, because it is not a chemical disinfectant, does not leave a residual and cannot be used to meet SWTR requirements regarding entry point and distribution system residuals.

Recommendations for Addressing this Issue

Free chlorine or chloramines can be used to maintain a residual disinfectant. Chlorine is effective against viruses and bacteria but can cause significant problems with Stage 2 DBPR compliance, especially in portions of the distribution system with long residence times where organic carbon is present. Chloramines as a residual disinfectant after UV disinfection have the potential to provide adequate distribution system residual and very low DBPs. Problems with chloramines include potential issues with nitrification, potential corrosion problems, and taste and odor issues if the chlorine-to-ammonia ratio is not maintained properly.

Power Quality Problems Can Disrupt Disinfection

A UV lamp can loose power in the event of a power interruption, voltage fluctuation, or power quality anomaly. Common causes of power quality problems include faulty wiring and grounding, weather-related damage, and power transfers to emergency generators or alternate feed (USEPA 2006b). Systems are required to monitor lamp status to ensure that reactors are operating within validated limits. Loss of power can result in the reactors operating off-specification.

Recommendations for Addressing this Issue

Systems should determine if their facility(s) experience power quality problems or is located in a remote area where power quality is unknown. If power quality may be a problem, EPA recommends that systems perform a power quality assessment to quantify and understand the potential for off-specification operation. Power quality assessments include contacting local power suppliers to obtain data on power quality and reliability, obtaining information on the power quality tolerance of the UV equipment under consideration, determining how long it will take UV reactors to function at full power after a power quality event, and determine if backup power or power conditioning equipment is needed (USEPA 2006b).

Requires Additional Training

Because UV reactors are operated differently than conventional chemical disinfection, training may be needed to ensure proper operation, monitoring, reporting, and maintenance of the UV disinfection equipment.

Recommendations for Addressing this Issue

Equipment vendors and state officials should be contacted early in the process regarding the appropriate training for UV disinfection. Systems considering UV should check with their state to determine whether state-specific monitoring requirements.

5.3.3 Recommendations for Gathering More Information

Read Case Study

Case Study # 12 – Ultraviolet Disinfection on page B-71 in Appendix B describes a surface water system with a 16 MGD plant that converted from chlorine to UV treatment to achieve its CT. The system uses a large river as its source and needed to reduce its DBPs. In anticipation of LT2ESWTR, it opted for UV because of the additional benefit that UV inactivates *Cryptosporidium*. One of the biggest challenges the system faced with the transition was providing the training needed to operate and maintain the UV system. This case study describes how the system addressed this and other issues it encountered as one of the first surface water systems of its size to switch over to UV.

See Additional References

Readers can turn to Chapter 7 for further references on this topic. Section 7.1.1 includes general references on water treatment, section 7.1.2 includes references on controlling DBP formation, and section 7.1.14 includes references on UV disinfection.

Consider Additional Monitoring

The following are some suggestions for additional monitoring that may benefit water systems implementing UV disinfection. The purpose of these monitoring suggestions is specifically to address and prevent potential simultaneous compliance issues. Monitoring should be done before the design process to allow for proper design of the system. Water system managers should discuss process control monitoring with the manufacturer of their UV units, their engineer, and other experienced utilities.

- ✓ Monitoring for UV absorbance, which is very important for UV disinfection performance and is required by the LT2ESWTR

- ✓ Periodic measurements of inorganic and organic chemicals, as applicable, in the water entering the UV unit. Tracking their concentrations will help a system make sure levels are low enough and will not interfere with UV disinfection. Some compounds with this potential are:

    - Iron
    - Manganese
    - Calcium
    - Magnesium
    - Aluminum
    - Dissolved Organic Carbon
    - Ozone

Consider Other Tools

In addition to water quality monitoring, there are additional tools listed in Chapter 6 that could help systems evaluate and improve their current water system in relation to the compliance issues they may face when modifying their treatment operations. Examples of tools that can be used when UV is used for Stage 2 DBPR compliance include:

- The “Ultraviolet Disinfection Guidance Manual” (USEPA 2006b) which provides guidance on the validation, selection, design, and operation of UV disinfection systems;
- The AwwaRF report “Integrating UV Disinfection Into Existing Water Treatment Plants” (Cotton 2005) which provides user-friendly web tools that will assist utilities in assessing important disinfection decisions and UV implementation issues;
- The AwwaRF report “Full Scale Implementation of UV in Groundwater Disinfection Systems” (Malley 2002) which provides specific guidance for the selection, design, and operation of UV systems; and
- Various cost estimation models that can be used to estimate the cost of implementing a new UV facility.

Readers are encouraged to read through Chapter 6 before making any final compliance decisions.

5.4 Chlorine Dioxide

Chlorine dioxide is an alternative chemical disinfectant that can be used to lower DBP production while maintaining adequate levels of inactivation. Because it is unstable, it is generated onsite using chlorine dioxide generators.

Chlorine dioxide has gained popularity because it produces relatively few THMs and HAAs. It is also very effective against bacteria, viruses, and *Giardia* cysts, and can provide some inactivation of *Cryptosporidium* oocysts at higher temperatures. The main drawback of chlorine dioxide is that the chlorine dioxide MRDL of 0.8 mg/L combined with an MCL of 1.0 mg/L for chlorite, the main byproduct of chlorine dioxide, limit the dose that can be applied. In addition, low water temperatures can make it more difficult to use chlorine dioxide.

5.4.1 Advantages of Chlorine Dioxide

Chlorine dioxide's advantages include:

- **Effectively inactivates bacteria, virus, and *Giardia* cysts; can achieve some *Cryptosporidium* oocyst inactivation;**
- **Less TTHM and HAA5 formation than chlorine;**
- **Effective oxidant for the control of iron, manganese, hydrogen sulfide, and phenolic compounds;**
- **May treat high-bromide, high-TOC waters better than chlorine or ozone; and**
- **Not significantly affected by pH values between 6 and 9.**

Effective Disinfectant

Chlorine dioxide is a strong oxidant and can therefore effectively inactivate a wide range of microbes. Exhibit 5.4 compares the required CT values of chlorine dioxide with those of chlorine and ozone. Chlorine dioxide is slightly less effective than chlorine against viruses and bacteria, but is more effective against *Giardia* and *Cryptosporidium*.

Exhibit 5.4 Required CT Values for Inactivation of Microorganisms by Chlorine Dioxide Compared with Other Chemical Disinfectants at 10°C and pH 6-9 (in mg-min/L)

Microbe	Inactivation Level	Chlorine Dioxide	Chlorine[1]	Ozone
Viruses	2-log (99.0%)	4.2	3	0.5
Viruses	4-log (99.99%)	25.1	6	1.0
Giardia	0.5-log (68.4%)	4	17	0.23
Giardia	3.0-log (99.9%)	23	104	1.43
Cryptosporidium	0.5-log (68.4%)	138	N/A	4.9
Cryptosporidium	3.0-log (99.9%)	830	N/A	30

Source: USEPA 2003a
N/A - not applicable. Chlorine is ineffective against *Cryptosporidium*.
1 - Chlorine CT values for pH 7

Chlorine dioxide can achieve some inactivation of *Cryptosporidium* oocysts. Required CT levels for *Cryptosporidium* inactivation are relatively high though, so achieving more than a half log inactivation is unlikely given restrictions on dose. See the following section for a further discussion of dose restrictions. Chlorine dioxide can, however, be a relatively low cost alternative for systems that require a 0.5 log *Cryptosporidium* inactivation to comply with the LT2ESWTR.

Less TTHM and HAA5 Formation

Chlorine dioxide provides a good alternative to chlorine for systems that wish to lower the formation of TTHM or HAA5. Pure chlorine dioxide does not form significant amounts of TTHM or HAA5. Most chlorine dioxide generators do produce some chlorine as a byproduct, however, so some TTHM and HAA5 will still be formed. The DBP of greater concern when chlorine dioxide is used is chlorite, which has a 1.0 mg/L MCL. See the discussion in the following section for more information on minimizing chlorite formation. Systems contemplating changing to chlorine dioxide will be required to perform a disinfection benchmark for viruses, *Giardia*, and *Cryptosporidium* and consult with the state to ensure adequate disinfection levels are maintained.

Effective Oxidant

Another advantage to chlorine dioxide is that it is a strong oxidant. It can effectively oxidize many compounds including iron and taste and odor compounds. Under the right pH conditions it can oxidize arsenic, which is often the first step in arsenic treatment. Oxidation of arsenic does not alone result in the removal of arsenic from water, but it enhances its removal during additional treatment. Systems that were previously using chlorine to pre-oxidize these chemicals may be able to achieve the same goals using chlorine dioxide, and simultaneously reduce TTHM and HAA5 to comply with the Stage 2 DBPR.

Not Significantly Affected by pH

The efficiency of chlorine dioxide does not vary significantly in the pH range of 6 to 9. This benefits systems trying to meet benchmarks since the CT achieved will not vary with pH. This also gives systems more flexibility with their treatment. They can adjust pH values to improve coagulation, reduce corrosion, or reduce DBP formation without concern for losing disinfection efficiency. It is possible, however, that some plants using enhanced coagulation or enhanced softening may fall outside the pH range of 6 to 9. See the following section for further discussion of these cases.

5.4.2 Potential Operational and Simultaneous Compliance Issues Associated with Chlorine Dioxide Use

Potential issues with using chlorine dioxide include the following:

- **Forms chlorite, a regulated DBP**
- **Reduced effectiveness at low temperature**
- **Chlorine dioxide MRDL of 0.8 mg/L**
- **Can form brominated DBPs**
- **Degrades when exposed to UV light**
- **Residual dissipates quickly**
- **Potential odor problems**
- **Requires additional training and safety concerns**

This section addresses these issues and provides recommendations for addressing them.

Chlorite Formation

One of the biggest disadvantages of using chlorine dioxide as a disinfectant is that it forms chlorite. The MCL for chlorite was set at 1.0 mg/L by the Stage 1 D/DBPR. Systems using chlorine dioxide must monitor daily at the entrance to the distribution system for chlorite. They must also collect 3 chlorite samples per month in the distribution system. As much as 70 percent of the chlorine dioxide added to water can break down to form chlorite. This limits the dose of chlorine dioxide that can be used and therefore the amount of inactivation that can be achieved. This especially limits *Cryptosporidium* inactivation, since the required CT values for *Cryptosporidium* are much higher than for other microbes.

High oxidant demand and high pH also lead to higher chlorite production. If there is substantial oxidant demand in a system's water due to natural organic matter (NOM) or reduced metals, the oxidant demand will consume the chlorine dioxide and form chlorite, but the chlorine dioxide consumed in this way will not achieve any disinfection. Systems then have to add higher chlorine dioxide doses to achieve sufficient inactivation, and as a result generate higher chlorite concentrations.

Water pH values above 9 also lead to increased production of chlorite. Systems with high pH as a result of enhanced softening or corrosion control may have trouble complying with the chlorite MCL.

One of the biggest disadvantages of using chlorine dioxide as a disinfectant is that it forms chlorite.

Recommendations for Addressing this Issue

There are several ways to minimize chlorite concentrations. Adding chlorine dioxide after the filters, after the oxidant demand has been reduced, can result in lower chlorite concentrations. In order to comply with the LT1ESWTR or IESWTR, systems must benchmark and check with the state before moving the point of disinfection. Systems using chlorine dioxide as a pre-oxidant may also reduce the water's oxidant demand by using pre-sedimentation before chlorine dioxide is injected.

Systems that increase pH during treatment should try to do so after the chlorine dioxide contact chamber. They may want to reduce the treated water's pH to below 9 before adding the chlorine dioxide.

Even if systems control pH and have no oxidant demand outside of microbial inactivation, 50 to 70 percent of the chlorine dioxide consumed will form chlorite. This puts an effective limit on the dose that can be applied. Most systems will not be able to apply chlorine dioxide doses of greater than 1.2 mg/L without risking exceeding the chlorite MCL. Systems that cannot achieve the desired inactivation with a chlorine dioxide dose of less than 1.2 mg/L may want to consider using another disinfectant in addition to chlorine dioxide to achieve the necessary inactivation. Another possibility is that the chlorite could be reduced using a reductant such as thiosulfate, which would then allow the use of higher chlorine dioxide doses.

Reduced Effectiveness at Low Temperatures

The disinfection effectiveness of chlorine dioxide is temperature sensitive. It is much less effective at colder temperatures. Exhibit 5.5 shows the temperature sensitivity of chlorine dioxide in terms of *Cryptosporidium* oocyst inactivation.

Exhibit 5.5 Effect of Temperature on the CT Required for *Cryptosporidium* Inactivation by Chlorine Dioxide

Temperature (^{o}C)	CT (in mg-min/L) for 0.5-log inactivation (69.3%)	CT (in mg-min/L) for 2.0-log inactivation
1	305	1275
10	138	553
25	38	150

Source: USEPA 2003a

As a result of this temperature dependence, systems in cold weather climates may not be able to use chlorine dioxide to meet the *Cryptosporidium* inactivation requirements of the LT2ESWTR.

Recommendations for Addressing this Issue

Systems may be able to achieve some inactivation by increasing the chlorine dioxide dose and then using a reducing agent such as thiosulfate to reduce the chlorite to chloride, or by using a second disinfectant. In general though, systems that regularly experience near freezing temperatures should probably investigate other disinfection techniques.

Chlorine Dioxide MRDL

Chlorine dioxide itself can have health effects at elevated levels. Therefore it has an MRDL of 0.8 mg/L. Systems using chlorine dioxide will have to monitor the chlorine dioxide residual daily at the entry point to the distribution system, before the first customer. Systems using chlorine dioxide may have to limit their doses to prevent exceeding the MRDL. If the daily entry point sample exceeds the MRDL, systems are required by the Stage 1 D/DBPR to monitor the chlorine dioxide residual in the distribution system.

Chlorite can react with excess chlorine in the distribution system to reform chlorine dioxide. Some systems may opt to boost with chlorine to maintain a residual in the distribution system. If doses are high enough, systems could exceed either the chlorine dioxide MRDL or the chlorite MCL. Reformed chlorine dioxide can also volatilize at consumer's taps and react with volatile organics to cause odor problems.

Systems that use chloramines for distribution residual may have difficulty measuring chlorine dioxide because chloramines can interfere with its measurement.

Recommendations for Addressing this Issue

If chlorine dioxide doses are kept below 1 mg/L, exceeding the MRDL should not be a problem. If reformation of chlorine dioxide is not desired, chloramines can be used in the distribution system instead of chlorine. If doses much higher than 1.2 mg/L are used, a reducing agent can be added to the water before it enters the distribution system to reduce any chlorine dioxide residual or chlorite to chloride. This will also prevent formation of chlorine dioxide in the system by booster addition of chlorine.

If a system intentionally re-forms chlorine dioxide by boosting with chlorine in the distribution system, the system should conduct bench scale tests to determine the correct chlorine dose to add to achieve an adequate residual without exceeding either the chlorine dioxide MRDL or the chlorite MCL. Systems should take into consideration the expected residence time in the distribution system. Although some small systems in Canada have maintained adequate residuals using doses of 0.4 to 0.6 mg/L of chlorine dioxide, other larger systems have found loss of residual at the end of the distribution system using similar doses (Volk et al. 2002b).

If a system is using chloramines to maintain a distribution system residual, there are amperometric titration techniques which can be used to determine between various chlorine species. Systems should consult *Standard Methods for the Examination of Water and Wastewater* (APHA, AWWA, and WEF 1998) for details of the method.

Can Form Brominated DBPs

Chlorine dioxide can oxidize bromide ions to bromine. The bromine can then react with organic matter to form brominated DBPs. Systems with high bromide concentrations that are near the Stage 2 DBPR limits for TTHM or HAA5 will need to take this into account.

Recommendations for Addressing this Issue

Systems with high bromide concentrations that are near the Stage 2 DBPR limits for TTHM or HAA5 can lower DBP formation by adding chlorine dioxide after the filters, where organic concentrations are lower. Enhancing coagulation will also lower the amount of organic matter available to react with chlorine dioxide after the filters. Systems that use chlorine dioxide for pre-oxidation may be able to achieve some organic removal by using pre-sedimentation basins. Systems with very high bromide can remove it using ion exchange columns, but this is rarely an economical solution.

Degrades When Exposed to UV Light

Chlorine dioxide is sensitive to UV light and will degrade to form chlorate when exposed to UV light. This will reduce chlorine dioxide residuals and therefore lower inactivation.

Recommendations for Addressing this Issue

Systems using chlorine dioxide can prevent degradation by light by covering the contact basin. If a building or hard cover are not cost-effective or require too much space, floating covers can shield the chlorine dioxide from the UV light. The manufacturer should be consulted in selecting the cover material to be sure it is compatible with chlorine dioxide.

Systems using chlorine dioxide and UV disinfection together should add the chlorine dioxide either after the UV reactor or sufficiently ahead of the reactor that there is no residual entering the reactor. Systems should not use the residence time of UV reactors to receive contact time credit for chlorine dioxide added earlier in the treatment process.

Residual Dissipates Quickly

Chlorine dioxide is highly reactive and will react with GAC and anthracite in filters. Chloride formed by the reaction of chlorine dioxide and GAC can also adsorb to the GAC and cause weaker binding elements to be released. See Section 4.1 for more information on GAC use. Chlorine dioxide is also volatile and can be lost in rapid mix basins or other unit processes that have high turbulence and are exposed to the atmosphere.

Recommendations for Addressing this Issue

Filters should not be used to achieve contact time for chlorine dioxide. Rapid mix basins can be used for contact time, but may require higher doses to achieve the same inactivation level. Adding the chlorine dioxide after filtration will avoid any unnecessary residual loss and will maximize the chlorine dioxide dose that is available for disinfection.

Systems adding chlorine dioxide as a pre-oxidant can add the chlorine dioxide in the coagulation basins. Systems with low alkalinity may see a slight rise in pH after chlorine dioxide addition.

Potential Formation of Odor-Causing Compounds

Chlorine dioxide residuals in customers tap water has been found to volatilize at the tap and to react with volatile organic compounds (VOCs) in customer's houses forming compounds with particularly bad kerosene-type odor (Hoehn et al. 1990). It can also sometimes give a strong chlorinous odor.

Recommendations for Addressing this Issue

The appearance of odors in customer's homes is difficult to predict and therefore prevent. Utilities can keep good customer complaint records and provide public education on what to do if such odors occur. Suggestions for dealing with odors in the household include improving ventilation and using carbon filters to remove the chlorine dioxide residual.

Additional Training Needed, Safety Concerns

The nature of chlorine dioxide and the chemicals used to generate it requires additional training and safety precautions to ensure safe operation of the treatment plant. Sodium chlorite is often used to generate chlorine dioxide. When acidified, it can produce large amounts of gaseous chlorine dioxide. Chlorine dioxide at concentrations greater than 0.1 ppm is toxic and can cause shortness of breath, coughing, respiratory distress, and pulmonary edema. Gaseous chlorine dioxide concentrations greater than 10 percent can be explosive. Sodium chlorite fires burn very hot and produce oxygen as a byproduct.

Recommendations for Addressing this Issue

Systems should contact their chlorine dioxide equipment manufacturer to schedule any necessary training. Sodium chlorite should be stored away from other chemicals, especially acids and reducing agents. It should be stored in an area made of fire resistant materials such as concrete. The area should be equipped with monitoring equipment to detect chlorine dioxide and other chlorine components in the atmosphere. Proper ventilation and scrubbers should be provided in the area. A special plan should be developed to respond to leaks or fires in the area and the necessary equipment to implement the plan, including respirators, should be stored and accessible outside the sodium chlorite storage area. If more than 1,000 pounds are stored on site the plan must be formalized into a Risk Management Plan (RMP) and OSHA's specific requirements for storage of chlorine dioxide must be satisfied.

5.4.3 Recommendations for Gathering More Information

Read Case Studies

Two case studies provided in Appendix B describe systems that switched to chlorine dioxide to reduce DBPs in their finished water and the simultaneous compliance challenges they encountered when making the switch.

Case Study #13 - Chlorine Dioxide for Primary Disinfection and Chloramines for Secondary Disinfection on page B-75 describes a surface water treatment plant in a wholesale system serving seven municipalities and approximately 92,000 people. The treatment plant switched from chlorine to chlorine dioxide as its primary disinfectant and from chlorine to chloramines for residual disinfection. In addition, the system uses chlorine dioxide intermittently as a pre-oxidant in its raw water. Among the challenges the system has encountered is being able to achieve sufficient *Cryptosporidium* inactivation to be granted LT2ESWTR credit and still comply with the Stage 1 DBPR's chlorite MRDL.

Case Study #14 – Chlorine Dioxide for Primary Disinfection and Chloramines for Secondary Disinfection on page B-81 describes a surface water system serving fewer than 10,000 people per day that also switched from chlorine to chlorine dioxide for CT and to chloramines for residual disinfection. The system, which is challenged by zebra mussels clogging its intake, found chlorine dioxide pretreatment works well as a replacement for the potassium permanganate previously used. It also adopted a monitoring program to watch for nitrification in its extensive distribution system.

See Additional References

Readers can turn to Chapter 7 for further references on this topic. Section 7.1.1 contains general references on water treatment, section 7.1.2 contains references on controlling DBP formation, and section 7.1.15 contains references on chlorine dioxide.

Consider Additional Monitoring

The following are some suggestions for additional monitoring that may benefit water systems using chlorine dioxide. The purpose of these monitoring suggestions is specifically to address and prevent potential simultaneous compliance issues. Water system managers should discuss process control monitoring with the manufacturer of their chlorine dioxide equipment or their engineer.

- ✓ If a system uses chlorine dioxide and has any kind of uncovered storage, chlorine dioxide residuals should be measured after the open storage to ensure that a sufficient chlorine dioxide residual has been maintained; and
- ✓ Customer complaints can be monitored to determine if chlorine dioxide residuals are causing problems.

Consider Other Tools

In addition to water quality monitoring, there are additional tools available in Chapter 6 to help systems evaluate and improve their current water system in relation to the compliance issues they may face when modifying their treatment operations. Examples of tools that can be used when chlorine dioxide is used for Stage 2 DBPR compliance include:

- The “Guidance Manual for Monitoring Distribution System Water Quality” (Kirmeyer et al. 2002) which can be used to assist water utilities in implementing a distribution system water quality data collection and analysis program, especially for chlorite and chlorine dioxide residuals;
- The AwwaRF report “Internal Corrosion of Water Distribution System” (AwwaRF and DVGW-Technologiezentrum Wasser 1996) which provides bench-scale and pilot testing protocols that can be used to evaluate changes in corrosion potential due to the switch to chlorine dioxide;
- The Standard Method 2350 (Oxidant Demand/Requirement) (APHA 1998) that provides step-by-step instruction for the determination of chlorine dioxide demand;
- The AwwaRF report “Water Utility Self-Assessment for the Management of Aesthetic Issues” (McGuire et al. 2004) which can be used to guide utilities in conducting self-assessment on their taste and odor issues caused by ozonation and to identify subsequent control strategies;
- The AwwaRF report “Tools and Methods to Effectively Measure Customer Perceptions” (Colbourne 2001) which describes tools that allow utilities to measure customer perceptions and changes in their opinions toward the use of chlorine dioxide;
- *Water/Wastewater Costs, Windows Version 3.0, (Wesner 2000)* which provides capital and O&M cost calculations for various water treatment processes based on user inputted design parameters; and

- EPA's *Microbial Toolbox Guidance Manual* (USEPA N.d.e) which describes technologies which can be used for compliance with the LT2ESWTR. The manual describes advantages and disadvantages for each technology and lists design and operating considerations.

Readers are encouraged to read through Chapter 6 before making any final compliance decisions

5.5 Primary and Residual Disinfectant Use

Different combinations of primary and residual (i.e., secondary) disinfectants can present different issues and concerns. For example, when ozone is used as the primary disinfectant followed by chloramines as the residual disinfectant, water systems should be aware that increased AOC concentrations resulting from ozonation may increase the likelihood of problems with nitrification in the distribution system. On the other hand, the chlorite ion produced by chlorine dioxide during primary disinfection may actually be effective at inactivating ammonia-oxidizing bacteria and, as a result, reduce nitrification in the distribution system.

This section follows a different format than many of the previous sections in this guidance manual. Exhibit 5.6 provides a summary table of the potential benefits and simultaneous compliance issues of the various combinations of primary and residual disinfectants. Brief paragraphs then follow the table, which describe noteworthy issues related to different disinfectant combinations.

Some systems have used chlorine dioxide as a disinfectant residual. Monitoring requirements, the MRDL for chlorine dioxide, the MCL for chlorite, and public notification requirements (some violations are considered acute and require immediate notification) make this a difficult option to implement to meet SWTR residual disinfection requirements. Thus, chlorine dioxide is not included as a residual disinfectant option in Exhibit 5.6.

Exhibit 5.6 Summary of Potential Benefits and Adverse Effects Associated with Different Combinations of Primary and Residual Disinfectants

Disinfection Switch (primary/residual, from ➜to)	Potential Benefits	Potential Adverse Effects	Drinking Water Regulation(s) Impacted
Chlorine/Chlorine ➜ Chlorine/Chloramines	• improved ability to maintain a disinfectant residual • lower TTHM and HAA5 • possible improved biofilm control • improved taste and odor	• excess ammonia can cause nitrification • possible elevated nitrite/nitrate levels • possible corrosion concerns • concerns for dialysis patients, fish owners, and other industrial customers	• Stage 2 DBPR • SWTR • TCR • LCR • Stage 1 DBPR • IESWTR • LT1ESWTR
Chlorine/Chlorine ➜ Ozone/Chlorine	• Lower TTHM and HAA5 • *Cryptosporidium* inactivation • better taste and odor control	• Bromate MCL concerns • additional bromate monitoring required • may increase brominated DBPs • increased AOC may enhance biofilm growth	• Stage 2 DBPR • Stage 1 D/DBPR • LT2ESWTR • TCR
Chlorine/Chlorine ➜ Ozone/Chloramines	• Lower TTHM and HAA5 • *Cryptosporidium* inactivation • improved ability to maintain disinfectant residual • may improve taste and odor	• nitrification may increase • possible elevated nitrite/nitrate levels • possible corrosion concerns • bromate MCL concerns • additional bromate monitoring required • increased AOC may enhance biofilm growth • concerns for dialysis patients, fish owners, and other industrial customers	• Stage 2 DBPR • Stage 1 D/DBPR • SWTR • LT2ESWTR • TCR • LCR
Chlorine/Chloramines ➜ Chlorine Dioxide/ Chloramines	• Lower TTHM and HAA5 • *Cryptosporidium* inactivation • *Giardia* and virus inactivation • can control iron and manganese • chlorite from chlorine dioxide may control nitrification	• additional chlorine dioxide and chlorite monitoring required • chlorite MCL concerns • chlorine dioxide MRDL concerns	• Stage 2 DBPR • Stage 1 DBPR • LT2ESWTR • LCR
Chlorine/Chloramines ➜ Ozone/Chloramines	• Lower TTHM and HAA5 • *Cryptosporidium* inactivation • improved taste and odor control • *Giardia* and virus inactivation	• increased AOC can encourage nitrification and biofilm growth • additional bromate monitoring required • ozone taste and odor issues • may create brominated DBPs • bromate MCL concerns	• Stage 2 DBPR • Stage 1 D/DBPR • LT2ESWTR • TCR • LCR

Ozone/Chlorine→ Ozone/Chloramines	• Lower TTHM and HAA5 • improved ability to maintain a disinfectant residual • improved taste and odor control *Giardia* and virus inactivation	• AOC may encourage nitrification • concerns for dialysis patients, fish owners, and other industrial customers • possible corrosion concerns	• Stage 2 DBPR • SWTR • TCR • LCR
Chlorine/Chlorine or Chlorine/Chloramines → UV/Chlorine or UV/Chloramines	• Lower TTHM and HAA5 • *Cryptosporidium* inactivation • *Giardia* and virus inactivation •	• UV less effective than chlorine at inactivating viruses • UV is not a pre-oxidant • less taste and odor control	• Stage 2 DBPR • SWTR • LT2ESWTR
Ozone/ Chlorine → Ozone/ UV/Chlorine	• additional *Cryptosporidium* inactivation • good taste and odor control • *Giardia* and virus inactivation	• ozone can lower UV transmittance	• LT2ESWTR

5.5.1 Noteworthy Issues About Disinfectant Combinations

Potential Drawback of Switching from Chlorine/ Chloramines to Ozone/ Chloramines

Changing to ozone as a primary disinfectant while maintaining chloramines as a secondary disinfectant may impact TCR compliance due to the reaction of ozone with natural organic matter to form AOC. Having already established distribution system practices for biofilm growth in chloraminated distribution water, public water systems making this disinfection practice modification should focus on the biological stability of their distribution system water.

In cases where the use of ozone as the primary disinfectant increases levels of AOC, biological stability in the distribution system could be disrupted. AOC provides nutrient value for cell metabolism. In a previously chloraminated system, control of nitrification may be achieved using one or more of the techniques described in Section 5.1.2. However, the additional nutrition provided by the increased AOC may require modification to the practices. Alternatively, biological filtration can be used to effectively reduce nutrient levels. Biological filtration can also reduce dissolved oxygen, which can lead to changes in redox chemistry in the system and potentially change scale chemistry, affecting corrosion control treatment.

Potential Benefit of Switching from Chlorine/ Chloramines or Ozone/ Chloramines to Chlorine Dioxide/ Chloramines

McGuire et al. (2006) provided field and laboratory evidence that the chlorite ion may be effective at controlling nitrification in distribution systems. The study showed that even low dosages of chlorite (0.1 mg/L) were effective at inactivating 3 to 4 logs of ammonia-oxidizing bacteria over several hours. Field investigations at five water systems in Texas showed that the presence of chlorite in the distribution systems resulted in less loss of chloramines and ammonia-nitrogen.

5.5.2 Recommendations for Gathering More Information

Read Case Studies

Case Study #13 - Chlorine Dioxide for Primary Disinfection and Chloramines for Secondary Disinfection on page B-75 describes a surface water treatment plant in a wholesale system serving seven municipalities and approximately 92,000 people. The treatment plant switched from chlorine to chlorine dioxide as its primary disinfectant and from chlorine to chloramines for residual disinfection. In addition, the system uses chlorine dioxide intermittently as a pre-oxidant in its raw water. Among the challenges the system has encountered is being able to achieve sufficient *Cryptosporidium* inactivation to be granted LT2ESWTR credit and still comply with the Stage 1 DBPR's chlorite MRDL.

Case Study #14 - Chlorine Dioxide for Primary Disinfection and Chloramines for Residual Disinfection on page B-81 in Appendix B provides an example of a small surface water system that switched from chlorine for primary and residual disinfection to chlorine dioxide for primary disinfection and chloramines for residual disinfection. The system pays close attention to the potential for nitrification in its distribution system as a result of the chloramines, and has developed a monitoring program and guidelines for action to prevent nitrification episodes. Chlorite is one of the parameters tracked closely in the distribution system. The system tries to take advantage of the possibility that chlorite may be toxic to nitrifying bacteria.

See Additional References

Readers can refer to Chapter 7 for more references on this topic. Section 7.1.1 contains references on general water treatment, section 7.1.2 contains references on controlling DBP formation, Section 7.1.12 contains references on chloramines, Section 7.1.13 contains references on ozone, Section 7.1.14 contains references on UV disinfection, and Section 7.1.15 contain references on chlorine dioxide.

Consider Tools

There are additional tools available to help systems evaluate and improve their current water system in relation to the compliance issues they may face when modifying their treatment operations. Readers are encouraged to read through Chapter 6 before making any final compliance decision.

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6 Making Compliance Decisions

This Chapter covers:

6.1 Introduction
6.2 Issues to Consider When Making a Compliance Decision
6.3 Tools for Gathering Information
6.4 Basic Approach for Implementing Regulatory Compliance Projects

The information provided in this chapter is meant to help water system managers and their regulators identify what issues should be considered before a change in treatment or operations is made. It also describes tools available to help systems collect information and a methodology for using information generated by these tools to make a compliance decision.

6.1 Introduction

To comply with the Stage 2 DBPR and LT2ESWTR, water systems will be making changes to their treatment and operations ranging from relatively small adjustments in how they run existing systems to major capital improvements. Systems should weigh the impacts of any modifications they are considering, including impacts related to the issues described in Chapter 2 and Section 6.2. They should identify what information they need to help them decide whether and how they can adjust their treatment to comply. If they do not have that information, they should identify what monitoring and/or studies are necessary to obtain it. Subsection 6.3.1 provides resources system managers can use as guidance for collecting data about their systems to help them make these decisions.

Subsection 6.3.3 describes available desktop studies that can be useful tools for decision-making. Subsection 6.3.4 lists resources available about bench-scale tests, including those describing proper jar testing applications and procedures. These are all relatively inexpensive ways for a system to determine whether it can comply by optimizing its existing treatment.

If a system opts to install new treatment, managers should proceed carefully and in an informed way. They too should consider the issues described in Chapter 2 and Section 6.2 and how those issues affect what treatment should be installed.

Some water systems will have more resources available than others for evaluating the potential impacts of a treatment change. The references provided in Section 6.3 give readers perspective on how involved and expensive different evaluation tools can be. Water system managers, particularly those with limited resources, are encouraged to take the time to make informed decisions about what evaluations should be performed before new treatment is installed.

Water system managers should examine the issues listed in Section 6.2 and determine which are most important to their system. Failing to consider the appropriate issues can cause unforeseen problems. For example, a system with historic low levels of arsenic in their water may decide to switch from chlorine to chloramines based on factors such as cost, compatibility with the existing process, and operator knowledge of the process; however, the change in oxidation reduction potential in the distribution system may cause arsenic adsorbed in distribution system scale to be released. In making determinations, it is important not only to evaluate the number of positives or negatives for a given compliance response but also to analyze the magnitude of each advantage or disadvantage.

Finally, simultaneous compliance is a necessary consideration when deciding how to proceed. System managers should use the information and references available throughout this and other guidance manuals to make Stage 2 DBPR and LT2ESWTR compliance decisions with confidence that all regulations will be met.

6.2 Issues to Consider When Making a Compliance Decision

As the previous chapters have indicated, numerous considerations should be taken into account when deciding on the best strategy for complying with a new regulation. Factors should be considered and balanced when coming to a conclusion that will satisfy all parties: system owners; regulatory agencies; customers; and other stakeholders. The earlier sections of this manual have laid out considerations for specific technologies. This section identifies issues to consider whenever any change is made to a water system, including changes that may not be discussed previously, such as novel technologies or seemingly minor operational changes.

Exhibit 6.1 summarizes the types of considerations that should be made before making changes, along with some direction as to what kind of information would help decision-makers during their review of those considerations.

Exhibit 6.1 Issues to Consider When Deciding How to Comply with Stage 2 DBPR and/or LT2ESWTR

Issue	Description of the Issue	Information to Help Systems Assess the Issue
Production Capability	• Quantity and quality of water may be an issue in arid or highly developed areas. • Systems operating at or near peak production capabilities are likely to be affected by decreases in production. • Some treatment technologies (e.g., enhanced filtration and anion exchange, membrane technologies) may lower production capacity. • Methods of lowering disinfection byproduct (DBP) production (e.g., changing storage tank fill/drain cycles, removing storage tanks) can affect the amount of storage available for droughts and fire fighting.	• Chapter 4 discusses issues with treatment technologies in more detail. • The amount of storage needed for uses such as droughts and fire fighting should be taken into account when making changes to distribution system storage. Hydraulic models as described in Section 6.3.2 can aid in making these determinations.
Compatibility with Existing Treatment Facilities	• A public water system (PWS) is a series of linked and inter-related processes that affect one another. Systems should consider the effects that changes or additions to any process in the system may have on other processes within the system. • Any modification that changes the chemical properties of the water such as pH, alkalinity, metals concentrations, or organic matter concentration will likely affect the coagulation and sedimentation process. • Adding new chemicals may cause corrosion of plant materials.	• Case studies #1-5, #7, and #9-14 in Appendix B provide examples of systems that faced issues as a result of changing existing treatment processes. • Many known effects of technologies are discussed in the preceding chapters. Other effects may be specific to a particular water quality or other site-specific variables, or to a technology not discussed in this guidance manual. • Tools discussed in Section 6.3 (e.g., bench studies, pilot testing) are important for determining potential effects of system changes.
Production of Residuals and Disposal Issues	• Some process changes can affect the composition or cause the production of residuals or other wastes. Disposal of additional waste should be taken into account when determining costs and in other considerations. • Systems should consider whether waste streams can be disposed of through sanitary sewer lines or if separate disposal means are required. Pretreatment requirements and requirements by the wastewater treatment plant should be investigated if sewer disposal is an option. • Process changes and changes in water quality (e.g., pH, alkalinity, metals concentrations, and organic matter) may affect the properties of residuals (e.g., the residual's density and its ability to be dewatered).	• Sections 3.6.2 and 3.7.2 provide more information on disposal of additional waste. • Combinations of jar tests and pilot tests can help determine changes that might occur and how best to deal with them, as described in sections 6.3.4 and 6.3.5, respectively. • Case studies #3 and #6 in Appendix B provide examples of residuals disposal issues.

Exhibit 6.1 Issues to Consider When Deciding How to Comply with Stage 2 DBPR and/or LT2ESWTR		
Issue	**Description of the Issue**	**Information to Help Systems Assess the Issue**
Site-Specific Issues	• System size and available resources vary widely and can impact compliance strategies. • Systems need to consider the number and skill of operators when making treatment decisions. • Systems need sufficient space for new technologies to be easily accessed for service and maintenance. • A system should consider how the addition of any new processes will affect the hydraulic gradient in the plant. • Location can be an important factor (e.g., price and availability of chemicals, delivery charges for equipment and chemicals, effect of the local climate on treatment processes).	• System-specific studies are critical to determining how various issues will affect a system. Some issues can be sufficiently answered through literature reviews and discussions with manufacturer representatives. Others will need to be investigated more thoroughly using the techniques discussed in Section 6.3. • The case studies in Appendix B illustrate how system-specific issues affect compliance decision-making.
Compatibility with Distribution System Materials	• Changes to water quality, especially to pH, alkalinity, or redox potential, can affect corrosion both in the plant and in the distribution system. • Some types of distribution system surfaces (e.g., highly scaled iron pipes) lend themselves to easily releasing scale materials into the water if changes are made to water quality. • Any treatment change should be analyzed to determine if it will change the corrosion rate of system materials.	• Section 6.3 discusses desktop studies along with bench and pilot methods such as pipe loop studies, which can be used to determine changes in corrosion rates associated with a given change. • Section 6.3.1 discusses water quality monitoring, which can provide warning if corrosion rates do change unexpectedly after a treatment modification. • Case studies #2 and #5 in Appendix B provide relevant examples. • Appendix D also includes evaluation tools that can be used to determine changes in corrosion rates.

Exhibit 6.1 Issues to Consider When Deciding How to Comply with Stage 2 DBPR and/or LT2ESWTR		
Issue	**Description of the Issue**	**Information to Help Systems Assess the Issue**
Compatibility with Distribution System Operations	• Treatment changes that alter the chemical make-up of the water can affect the distribution system and may require changes in its operation. • Systems should consider corrosion issues and microbial stability of the system (some chemicals added to the water may promote microbial growth in the distribution system). Systems using chloramines may have an increased risk of nitrification problems. • Systems may need to make distribution system changes (e.g., more frequent flushing, reducing residence times) to counter increased microbial activity.	• Section 5.1.2 describes the nitrification problem with chloramines. • Section 6.3 describes models that can help to predict and circumvent problems such as nitrification. • Case studies #1, 2, 5, 9, 10, 13, and 14 discuss distribution system issues that were raised as a result of treatment changes.
Environmental Issues	• Changes to treatment or system operations may present environmental issues (e.g., change to flushing procedures to remove chloramines, which are toxic to fish, before water is discharged to natural waters). • Constituents added to drinking water may raise issues at the wastewater treatment plant (WWTP) (e.g., metals such as zinc, used in some corrosion inhibitors, may inhibit the denitrification process at the WWTP) because some treated water eventually ends up in the sewer system. WWTPs may also have discharge permit limits for water quality parameters like pH, metals, and phosphorus. • If a system needs to purchase new land for a treatment process or wants to change sources, environmental issues may arise such as the presence of wetlands or endangered species; discharges to a stream or surface water body (e.g. filter backwash water, well development water)	• Systems should review environmental regulations and WWTP requirements before making any major changes. Related environmental regulations may include SDWA Source Water Assessment Program and Wellhead Protection Program (State primacy agency); state regulations on wetland protection and river protection; and local zoning ordinances. • Case study #6 in Appendix B addresses a possible radiation exposure issue for workers handling radioactive water treatment residuals.

Exhibit 6.1 Issues to Consider When Deciding How to Comply with Stage 2 DBPR and/or LT2ESWTR

Issue	Description of the Issue	Information to Help Systems Assess the Issue
Consumer Driven Issues	• Changes may result in consumer complaints about tastes, odors, or colored water, which can arise from many different factors. Changes in water chemistry can cause corrosion, causing colored water at the tap. Tastes and odors can result from high disinfectant doses or from microbial activity encouraged by water chemistry changes. • Changes in water rates require good communication • Good public education is important for public health protection and can head off consumer complaints.	• Section 5.1.2 discusses issues customers need to understand about use of chloramines. • Sections 6.3.4 and 6.3.5 describe bench-scale and pilot testing which help predict if changes will cause undesired outcomes at the consumer's tap. • Section 6.3.8 provides some resources for planning, such as public education efforts. • Case studies #5, 8, 11, and 14 in Appendix B discuss relevant examples.
Preference of Operations Staff	• Operator preferences for selecting a compliance option may be based on manpower and training requirements, safety concerns, monitoring requirements, chemical feed methods, the amount of automation, and equipment positioning.	• Systems should solicit input from operations staff, since they are responsible for the day-to-day implementation of any changes, can raise valid concerns that others have not considered during the planning process, and understand the implications for training. • Case studies #10-12 in Appendix B discuss the operational needs and implementation issues with UV treatment.
Consecutive System Requirements	• Systems selling some or all of their water to other systems will have to take into account the needs of the purchasing systems, which may not have treatment themselves. • Consecutive (purchasing) systems may have large distribution systems with long residence times. Water that is delivered may meet total trihalomethane (TTHM) maximum contaminant levels (MCLs) at delivery but may exceed them nearer the end of the distribution system. • Mixing different types of disinfectant residuals can cause problems if not done very carefully.	• EPA's *Consecutive Systems Guidance Manual for the Stage 2 DBPR* (USEPA N.d.b) will provide helpful information that guides decision-making for consecutive systems.
Cost	• Cost can be a driving force behind selection of compliance strategies	• Section 6.3.7 describes several computer models that can help with costing various technologies.

6.3 Tools for Gathering Information

The objective of this section is to provide examples of tools that can assist utilities to evaluate and improve their current water system in relation to compliance with Total Coliform Rule (TCR), Lead and Copper Rule (LCR), LT2ESWTR, and Stage 2 DBPR. These tools include computer software, models, technical publications, and research reports that can be acquired through public domains, non-profit organizations, or private companies. While some of the tools can be obtained freely from government agencies or the internet (such as reports and guidance manuals from EPA), the acquisition of some tools may either require member subscription (such as reports from AwwaRF) and/or fees (such as AWWA publications and proprietary software).

These tools are organized into the following eight categories:

- Water quality monitoring
- Hydraulic and water quality modeling for distribution systems
- Desktop evaluations
- Bench-scale testing
- Pilot testing
- Full-scale applications
- Cost estimation
- Community preferences

A subsection is dedicated to each of these categories and a brief introduction is included to describe the purpose of tools in that category and how they relate to other subsections.

This document does not intend to provide a comprehensive list of tools that may be used to assist with simultaneous compliance, but rather to provide examples of available tools. Readers of this document should consult with regulatory agencies and professional organizations for other similar tools and updated information.

6.3.1 Water Quality Monitoring

Tools included in this section provide guidance and methodologies for monitoring water quality in water supplies, water treatment facilities, and transmission and distribution systems. The first five tools are EPA documents that describe water quality sampling requirements for various regulations. Utilities should consult with these documents to meet the minimum regulatory monitoring requirements.

- **Total Coliform Rule: A Quick Reference Guide (USEPA 2001f).** This EPA document provides updated information on water quality monitoring requirements for the TCR. This document is included in Appendix A and can also be obtained from the following EPA Web site: http://www.epa.gov/safewater/disinfection/tcr/pdfs/qrg_tcr_v10.pdf

- **A Small System Guide to the Total Coliform Rule (USEPA 2001g).** This EPA document provides guidance on monitoring requirements for small systems that serve 3,300 or fewer people. This document can be obtained from the following EPA Web site: *http://www.epa.gov/safewater/smallsys/small-tcr.pdf*.

- **Drinking Water Regulations: National Primary Drinking Water Regulations for Lead and Copper Rule (USEPA 2000b) & Lead and Copper Rule Minor Revision Fact Sheet (USEPA 1999i). Lead and Copper Rule: A Quick Reference Guide (USEPA 2004g).** These documents summarize the monitoring requirement of the LCR and can be found on the following EPA web site: http://www.epa.gov/safewater/lcrmr/index.html . The LCR quick reference guide is also included in Appendix A. In addition, EPA proposed minor revisions to the LCR in 2006 that affect monitoring requirements. The proposed changes are summarized in a fact sheet available at the EPA Web site listed above.

- **Source Water Monitoring Guidance Manual for Public Water Systems (USEPA 2006f).** This EPA guidance manual for PWSs affected by the rule provides information on laboratory contracting, sample collection procedures and data evaluation, and interpretation. This guidance manual also provides information on grandfathering requirements for *Cryptosporidium* and *E. coli* data under the LT2ESWTR. The guidance manual is available at the following EPA web site: http://www.epa.gov/safewater/disinfection/lt2/pdfs/guide_lt2_swmonitoringguidance.pdf

- **The Stage 2 DBPR Initial Distribution System Evaluation Guidance Manual (USEPA 2006a).** This EPA document provides distribution system water quality monitoring requirements for the Stage 2 DBPR. This guidance manual describes the monitoring frequency, number of sampling locations, and the methodologies for selecting appropriate sampling locations for TTHM and HAA5. The guidance manual is available at the following EPA web site: http://www.epa.gov/safewater/disinfection/stage2/compliance_idse.html

- **Initial Distribution System Evaluation Guide for Systems Serving < 10,000 People (USEPA 2006g).** This EPA document provides distribution system water quality monitoring requirements for the Stage 2 DBPR for small systems. This guidance manual describes the monitoring frequency, number of sampling locations, and the methodologies for selecting appropriate sampling locations for TTHM and HAA5. It is available at the following web site: http://www.epa.gov/safewater/disinfection/stage2/compliance_idse.html.

- **Design of Early Warning and Predictive Source-Water Monitoring Systems (AwwaRF Report 90878, Grayman, Deininger and Males 2001).** This research report provides guidance on the development of early warning systems for real-time source water contaminant monitoring. These systems will allow utilities to predict water quality events in the source water that may require subsequent treatment adjustment in the water treatment facilities.

- **Guidance Manual for Monitoring Distribution System Water Quality (AwwaRF Report 90882, Kirmeyer et al. 2002).** This document provides water utilities with guidance on how to design and implement a distribution system water quality data collection and analysis program. This document features a comprehensive approach for collecting and analyzing water quality information, providing important input to costly infrastructure improvements, documenting benefits of operational procedures, and addressing consumer complaints.

- **Methods for Real-Time Measurement of THMs and HAAs in Distribution Systems (AwwaRF Report 91003F, Emmert et al. 2004).** This document summarizes existing technologies and methods that can be used to quantify concentrations of total THMs and the sum of the five regulated HAA5 in near-real time. Some of the methods are also capable of quantifying individual THM and HAA species.

- **Optimizing Corrosion Control in Water Distribution Systems (AwwaRF Report 90983, Duranceau, Townley and Bell 2004).** This report demonstrates the use of a multi-element sensor electrochemical technique for instantaneously monitoring corrosion and optimizing corrosion control in water distribution systems. This document also describes the uses of real-time corrosion sensors to screen various corrosion inhibitors.

- You may go to the following documents for national occurrence information to determine how your source water compares with source waters of other systems, and to get a sense of the technologies being commonly used by water systems with source water quality similar to yours.

    - USEPA. 2005e. Stage 2 Occurrence Assessment for Disinfectants and Disinfection Byproducts. EPA 815-R-05-011

    - USEPA. 2005a. Occurrence Assessment for the Final Stage 2 Disinfectants and Disinfection Byproducts Rule. Prepared by The Cadmus Group, Inc. Contract 68-C-99-206. EPA 815-R-06-002.

    - McGuire, M.J., J.L. McLain, and A. Obolensky. 2002. *Information Collection Rule Data Analysis.* AwwaRF Report 90947. Project #2799. Denver: AwwaRF.

6.3.2 Hydraulic and Water Quality Modeling for Distribution System

While documents listed in the previous section provide guidance on monitoring water quality, tools described in this section provide means to predict and model water quality changes in the distribution system based on the calculation of hydraulic retention time (water age), kinetics of water chemistry, and parameters that could affect water chemistry (e.g., temperature, pipe material, etc.). In addition to water quality modeling, most of these tools are also capable of hydraulic modeling. Results from these modeling exercises can assist utilities in projecting distribution system water quality and planning for simultaneous compliance.

- **EPANET (USEPA 2002b). Developed by EPA, EPANET 2.0** is a Windows-based computer program that performs extended period simulation of hydraulic and water quality behavior within pressurized pipe networks. It is available at the following EPA Web site: *http://www.epa.gov/ORD/NRMRL/wswrd/epanet.html*. Several software companies (including DHI, MWH Soft, Haestad Methods, and Wallingford Software) use EPANET as the foundation to develop their proprietary versions of hydraulic and water quality modeling tools. These commercial programs provide similar functions to that by EPANET, but may be more flexible, and user-friendly.

- **SynerGEE® Water. Developed by Advantica, SynerGEE Water** is a simulation software package for modeling and analyzing water distribution systems. It is capable of conducting steady state analysis, dynamic analysis, and the analyses of water age, source contribution, water quality, fire flow, and pump operating costs.

- **Advanced Water Distribution Modeling and Management (Walski et al. 2003)**. Written by industry experts, it provides practical resources for engineers and modelers. Walks through the modeling process from start to finish - from data collection and field-testing to using a model for system design and complex operational tasks. Explores transient analysis, GIS technology applications, and water system vulnerability and security.

- **Water Quality Modeling of Distribution System Storage Facilities (AwwaRF Report 90774, Grayman et al. 2000).** This document describes procedures that can be used to characterize water quality conditions and changes in water storage reservoirs. This report also provides a hydraulic model with a water quality model that can be used to determine the effects of daily fill and draw cycles. Optimum design and operation of distribution system tanks and reservoirs is also addressed.

- **Predictive Models for Water Quality in Distribution Systems (AwwaRF Report 91023F, Clement et al. 2005).** This research report provides a comprehensive review of the current state of predictive water quality modeling covering water quality processes models for corrosion and metal release, discoloration, disinfectant decay, DBPs, and microbial water quality. This review also describes how these models can be applied to distribution networks, including water quality network models, storage tank models, and zone level models.

- **Computer Modeling of Water Distribution Systems Second Edition (AWWA Manual M32) (AWWA 2004a).** This manual provides step-by-step instructions for the design and use of computer modeling for water distribution systems. Distribution system operators can build an accurate and detailed “virtual” model of the system using computer software. Computer models can help the operators to uncover problems and explore different scenarios to solve the problems without actually entering or changing the physical distribution system. This manual also includes results from a survey of U.S. and Canadian water utilities on future trends of water distribution and water quality modeling.

6.3.3 Desktop Evaluations

Desktop evaluation tools included in this section can be used to assist utilities in evaluating and optimizing treatment strategies to comply with LT2ESWTR and Stage 2 DBPR. These tools are particularly helpful in identifying the best combination of treatment components for simultaneous regulatory compliance.

- **Water Treatment Plant Model for MS Windows 3.1: Version 1.55 (USEPA 1994b).** The Water Treatment Plant Model (WTP) was originally developed in support of the Stage 1 Disinfectant/Disinfection Byproducts Rule. It was prepared with the understanding that the predictions should reflect the central tendency for treatment. It is not to be construed that the results from the model will necessarily be applicable to individual raw water quality and treatment effects at unique municipalities. The model does not replace sound engineering judgment based on site-specific treatability data to evaluate the best manner in which to address the requirements of the SWTR or D/DBP rules.

  Originally developed by EPA in 1992 to support the Stage 1 D/DBP Rule, the Water Treatment Plant Model was updated in 1994 to include more data and alternative treatment processes to assist utilities in achieving total system optimization (TSO), i.e., a method by which treatment processes can be implemented such that a utility meets the required levels of disinfection while maintaining compliance with requirements of Stage 1 and, potentially, Stage 2 DBPR. Available on EPA's website: http://yosemite.epa.gov/water/owrccatalog.nsf/e673c95b11602f2385256ae1007279fe/80acea46c3412a1185256b06007259ee!OpenDocument The model was further updated in 1999 to include new data and to update treatment processes. The latest version of the model (USEPA 2001i) is available by calling 1-800-426-4791.

- **Operational Evaluation Guidance Manual (USEPA N.d.f).** The purpose of this guidance manual is to provide technical information and guidance for water systems and states to use for identifying and reducing significant excursions of DBP levels.

- **Self-Assessment for Treatment Plant Optimization, International Edition. (Lauer 2001).** Optimize conventional treatment processes without investing in major capital improvements with this detailed guidebook. The guide provides procedures for optimizing particulate removal and disinfection through improvements in administration, maintenance, design, and operations.

- **Partnership for Safe Water Information Center.** The Partnership for Safe Water is a voluntary program organized collaboratively among EPA, AWWA, and other drinking water organizations to optimize water treatment plant performance above and beyond regulatory requirements. The Information Center, found at the following Web site, http://www.awwa.org/science/partnership/InfoCenter/, includes self-assessment checklists, sample reports, and fact sheets to help a water system get started.

- **The Rothberg, Tamburini & Winsor Blending Application Package 4.0 (AWWA 2001a).** This new RTW program is the successor of *Model for Water Process and*

Corrosion Chemistry 4.0. This computer program is developed to simplify the task of evaluating water chemistry associated with precipitation/coagulation and corrosion potential of water. The model provides prediction on the change of water quality (such as pH, hardness, alkalinity, and Langelier Saturation Index) in response to the changes in operating conditions. The new version can handle more than one water source under multiple blending scenarios. Although the RTW model adequately predicts the changes in water quality, any intent of correlating these information to actual corrosion potential should also include more detail and direct corrosion assessment as described in other sections of this document.

- **Metals Solubility Prediction Tools.** Additional models have been developed to evaluate the solubility of metals in the distribution system. The AwwaRF report, *A General Framework for Corrosion Control Based on Utility Experience and Control of Pb and Cu Corrosion By-Products Using CORRODE Software.* (Edwards and Reiber 1997a, b) includes chemical equilibrium software that can be used to identify causes of corrosion problems and test the validity of different corrosion control strategies. The USGS PHREEQC is a computer program designed to perform a wide variety of low-temperature aqueous geochemical calculations. Information on PHREEQC is available on the USGS website at *http://wwwbrr.cr.usgs.gov/projects/GWC_coupled/phreeqc/*

6.3.4 Bench-Scale Testing

This section includes bench-scale testing procedures and methods for acquiring technical information on water quality, treatment efficacy, and internal corrosion potential. This information is critical to water quality modeling and system evaluation and optimization. Five categories of bench-scale testing methods are presented in this section, including:

- Disinfectant Demand and Decay
- DBP Growth and Decay
- Taste and Odor Profiles
- Jar/Column Testing Procedures
- Internal Corrosion Assessment

Each of these bench-scale testing tools is described below.

Disinfectant Demand and Decay

- **Standard Method 2350, Oxidant Demand/Requirement (American Public Heath Association (APHA), AWWA, and Water Environment Federation (WEF) 1998).** Information on chlorine demand in the transmission and distribution system is critical to the assurance of public health as well as an effective internal control practice. Increasing chlorine dosage to compensate excessive chlorine demand may also result in high DBP formation. This standard method provides step-by-step instruction on four methods for the determination of oxidant demands: one method each for chlorine and chlorine dioxide and two methods for ozone (batch and semi-batch methods).

DBP Formation and Decay

- **Field and material-specific simulated distribution system testing as aids to understanding trihalomethane formation in distribution systems (Brereton and Mavinic 2002).** This paper presents results from a comprehensive study using an extensive field monitoring program and an improved simulated distribution system (SDS) bench-scale test. The SDS bench test includes the potential increased chlorine demand caused by internal pipe walls in the evaluation of DBP formation. During field testing, this study compared both pre-formed THM and THM formation potential among several distribution system locations to reduce inherent uncertainties associated with the complexities of network hydraulics, leaving exposure to the internal pipe environment as the primary factor of interest. Findings in this paper suggest the reliability of using the material-specific SDS (MS-SDS) test is a better representation of DBP evolution in a real distribution system. The MS-SDS test is readily adaptable for pilot-plant studies where real distribution system conditions are inaccessible. This article can be acquired from the following internet Web site: *http://pubs.nrc-cnrc.gc.ca/cgi-bin/rp/rp2_abst_e?cjce_l01-074_29_ns_nf_cjce*.

- **Simulated Distribution System DBP development procedure**

  - *Predicting the formation of DBPs by the simulated distribution system* (Koch et al. 1991). This study developed a simulated distribution system (SDS) method that can be used to predict the amounts of DBPs that would form in a distribution system. Key parameters (including chlorine dosage, incubation temperature, and incubation holding time) are chosen to simulate the conditions of the treatment plant and the distribution. Results from this study show good correlation between the SDS samples and the samples collected from the distribution systems.

  - *Assessing DBP yield: uniform formation conditions* (Summers et al. 1996). This paper presents a new chlorination approach, the uniform formation conditions (UFC) test. The UFC test can be used to assess disinfection DBP formation under constant, yet representative conditions. Results from this study suggest that UFC test can be used for a direct comparison of DBP formation among different waters and allows the evaluation of how treatment changes affect DBP formation in a specific water.

Taste and Odor Profiles

- **Practical Taste-and-Odor Methods for Routine Operations: Decision Tree (AwwaRF Report 91019, Burlingame et al. 2004)**. This report describes the existing and newly developed sensory methods for monitoring the taste-and-odor quality of drinking water, as well as the odor quality of source or partially-treated water, in order to understand the reasons for customers' attitudes and complaints, to make decisions for treatment, to track problems to their sources, and to provide early warning of problems that are expected to recur. The new methods are described in detail in this report while existing methods are already described in Standard Methods for the Examination of Water and Wastewater (APHA 1998). The new methods provide early warning to geosmin and 2-MIB, information about treatment, information for the approval of new installations in distribution, and the confirmation of customer complaints.

- **Water Utility Self-Assessment for the Management of Aesthetic Issues (AwwaRF Report 90978F, McGuire et al. 2004).** This report provides guidance for utility to conduct self-assessment on its T&O control strategies. This self-assessment tool improves a utility's ability to quickly identify the source of problems, implement control strategies, and communicate with its stakeholders.

Jar/Column Testing Procedures

- **Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual, Section 3: The Step 2 Procedure and Jar Testing (USEPA 1999h).** This document provides procedures for conducting jar testing to determine the optimum coagulation conditions for achieving desirable total organic carbon (TOC) removal and coagulated/settled water turbidity. This document can be found at the following EPA Web site: *http://www.epa.gov/safewater/mdbp/coaguide.pdf*.

- **Procedures Manual for Polymer Selection in Water Treatment Plants (AwwaRF Report 90553, Dentel et al. 1989).** This manual describes the bench-scale testing protocols for the selection of coagulants as well as the appropriate types of polymer for coagulant aids, filter aids, and sludge dewatering aids.

- **Operational Control of Coagulation and Filtration Processes (AWWA Manual M37, AWWA 2000).** This manual provides information on standard jar testing procedure for bench-scale coagulation testing.

- **Enhanced and Optimized Coagulation for Particulate and Microbial Removal (AwwaRF Project #155, Bell et al. 2001).** This research project evaluated the effect of enhanced and optimized coagulation on particulate and microbial removal. This study demonstrates the use of bench-scale studies on 18 waters corresponding to the EPA TOC – alkalinity matrix and removal of protozoan cysts and oocysts, viruses, enteric bacteria, spores, and bacteriophage. The bench-scale jar testing protocol described in this report can be used to determine the optimum coagulant type, coagulant dose, and coagulation pH for the compliance of Stage 2 DBPR, as well as LT2ESWTR and TCR.

- **Design of Rapid Small-Scale Adsorption Test for a Constant Diffusivity (Crittenden et al. 1986)** This paper describes the fundamental theory and bench scale testing procedure for using a small adsorptive media column to quickly predict effective GAC adsorption capacity for specific organic compounds in full-scale operation. This technique, known as RSSCT, has been widely accepted by the chemical engineering industry and has also been used to estimate useful GAC life time when used for the removal of aquatic organic contaminants.

- **Prediction of GAC Performance Using Rapid-Small Scale Column Tests (AwwaRF Project #230, Crittendon 1989).** This document describes the use of

RSSCT techniques to predict full-scale GAC useful life time when it is used to remove dissolved organic matter in drinking water source. This report also demonstrates how to use pilot-scale testing data to further refine the RSSCT prediction.

Internal Corrosion Assessment

- **Internal Corrosion of Water Distribution Systems (AwwaRF Report 90508, AwwaRF and DVGW-Technologiezentrum Wasser 1996).** This report covers a wide range of topics related to internal corrosion, such as corrosion principles, corrosion of various materials including copper alloys and solder, mitigation of corrosion impacts, assessment technologies, and approaches to corrosion control studies. This document also describes a bench-scale testing protocol of using various techniques (such as electrochemical techniques and coupon techniques) to evaluate corrosion potential. Other useful topics covered by this report include types of chemicals used for corrosion control, corrosion assessment options for metal plumbing materials, water quality conditions that affect corrosion of various types of materials, and benefits and drawbacks of bench testing versus flow-through pipe loops.

6.3.5 Pilot Testing

Prior to implementing a new technology, some systems may conduct pilot testing to evaluate technology performance under different design and operating conditions. Tools described in this section provide guidelines on how to conduct pilot testing. Since technology development proceeds at a very fast pace in the water industry, to ensure a successful project, utilities are strongly encouraged to consult with experienced engineers, reputable equipment providers, and regulatory agencies when planning a pilot testing program.

- **Membrane Filtration Guidance Manual (USEPA 2005b).** The purpose of this guidance manual is to provide technical information on the use of membrane filtration and application of the technology for compliance with the LT2ESWTR, which would require certain systems to provide additional treatment for Cryptosporidium. Section 6 of this guidance manual provides general guidelines for membrane pilot testing. Utilities who are considering using membrane technology to comply with LT2ESWTR should consult with this document before conducting on-site pilot testing and membrane selection. This document can be found at the following EPA Web site: *http://www.epa.gov/safewater/disinfection/lt2/compliance.html*

- **Long Term 2 Enhanced Surface Water Treatment Rule: Microbial Toolbox Guidance Manual (USEPA N.d.e).** While there is no specific standardized pilot testing protocol developed for each of the treatment processes identified in the LT2ESWTR Toolbox, with the exception of UV and membranes, this Toolbox Guidance Manual provides general guidance on the Demonstration of Performance (DOP) protocol that can be used to develop a specific pilot testing protocol for each treatment technology of interest. The final version of the document will be posted on EPA’s Web site: *http://www.epa.gov/safewater/disinfection/lt2/compliance.html*

- **Internal Corrosion of Water Distribution Systems (AwwaRF Report 90508, AwwaRF and DVGW-Technologiezentrum Wasser 1996).** As described in the Bench-Scale Testing section, this report provides a wide range of useful information on internal corrosion, including the description of an on-site pilot testing protocol for using a single-pass pipe loop tester to evaluate corrosion potential.

6.3.6 Full-Scale Applications

This section provides useful guidelines and tools for utilities to conduct treatment plant assessment and optimization. The goals for these exercises are to improve treatment performance and to comply with multiple regulations without major capital expenditure. Treatment enhancement through these practices is usually achieved by optimizing operating conditions and minor equipment updates or additions. Major capital improvement, such as the construction of a new membrane facility, is not within the scope of these plant optimization protocols, but may be needed after other options are exhausted.

- **Comprehensive Performance Evaluations (CPE*).* *Optimizing Water Treatment Plant Performance Using the Composite Correction Program* (USEPA 1998a).** This handbook consists of two components: the Comprehensive Performance Evaluations (CPE) and Comprehensive Technical Assistance (CTA). The CPE provides a set of tools that assist a utility to review and analyze its performance-based capabilities and associated administrative, operations, and maintenance practices. The goal of CPE is to help a utility to identify factors that might adversely impact a plant's ability to achieve permit compliance without major capital improvements. The CTA provides guidance for the performance improvement phase once the CPE identifies performance improvement potential. Information on this EPA manual can be found at the following EPA Web site: *http://www.epa.gov/ORD/NRMRL/pubs/625691027/625691027.htm*.

- **Partnership for Safe Water Information Center.** The Partnership for Safe Water is a voluntary program organized collaboratively among EPA, AWWA, and other drinking water organizations to optimize water treatment plant performance above and beyond regulatory requirements. The Information Center, found at the following Web site, http://www.awwa.org/science/partnership/InfoCenter/ includes self-assessment checklists, sample reports, and fact sheets to help a water system get started.

- **Texas Optimization Program (TNRCC 2005).** The Texas Optimization Program (TOP) is a voluntary, non-regulatory program designed to improve the performance of existing surface water treatment plants without major capital improvements. Information on TOP can be found at the following Web site: http://www.tceq.state.tx.us/permitting/water_supply/pdw/swmor/top/.

- **Self-Assessment for Treatment Plant Optimization (Lauer 2001).** This guidebook presents protocols on how to optimize conventional treatment plants without investing in major capital improvements. This document provides procedures for optimizing particulate removal and disinfection through improvements in administration, maintenance, design, and operations.

- **Ultraviolet Disinfection Guidance Manual (USEPA 2006b).** Similar to the Membrane Filtration Guidance Manual, this manual provides guidance on the validation, selection, design, and operation of ultraviolet (UV) disinfection to comply with treatment requirements under the LT2ESWTR. The key to the manual is EPA's recommended protocol for validation of UV reactors. The document is posted on EPA's web site: http://www.epa.gov/safewater/disinfection/lt2/pdfs/guide_lt2_uvguidance.pdf

- **Full Scale Implementation of UV in Groundwater Disinfection Systems (AwwaRF Report No. 90860, Malley et al. 2002).** This document identifies key issues related to full-scale UV implementation, including the importance of UV reactor hydraulic design, water quality evaluation, sensor calibration, and proper cleaning techniques to insure optimal UV performance. The report provides specific guidance for the selection, design, and operation of UV systems.

- **Integrating UV Disinfection Into Existing Water Treatment Plants (AwwaRF Report No. 91086. Cotton et al. 2005.).** This document provides user-friendly web tools that will assist utilities in assessing important disinfection decisions and UV implementation issues. This report also finds that electric power quality will most likely not cause a water utility to violate the regulatory requirements on UV application; however, power quality problems may reduce operational flexibility as well as UV lamp operations. The analysis protocol for the *Cryptosporidium* downtime and off-specification risk assessment could be used to assist regulators in developing criteria based on *Cryptosporidium* occurrence and risk.

- **Handbook of Public Water Systems, Second Edition (HDR Engineering Inc. 2001).** This handbook provides detailed engineering design information for various drinking water treatment processes, including granular activated carbon.

- **Integrated Membrane Systems (AwwaRF Report No. 90899, Schippers et al. 2004).** This document provides guidance on the selection, design, and operation of an integrated membrane system that can function as a synergistic system for removing microbiological contaminants and DBP precursors. The integrated system may include membranes (including RO, NF, UF, and MF) and any pre- or post-treatment. This document also provides procedures for bench and pilot testing for membrane elements.

- **Integrating Membrane Treatment in Large Water Utilities (AwwaRF Report 91045F, Brown and Hugaboom 2004).** This study addresses issues related to the integration of low pressure membranes into existing or planned water treatment facilities. Results from this study can be used as guidance for membrane layout, piping, cost comparison, and operations and maintenance.

- **NOM Rejection by, and Fouling of, NF and UF Membranes (AwwaRF Report 90837, Amy, Clark and Pellegrino 2001).** NF membranes can effectively remove natural organic matter (NOM) from a water supply, while ultrafiltration provides very limited NOM removal capability. This report provides information on the selection of appropriate membranes to achieve high NOM rejection, and also presents information on how water quality (such as the presence of calcium and pH) and operational conditions might affect NOM rejection by NF membranes.

- **Evaluation of Riverbank Filtration as a Drinking Water Treatment Process (AwwaRF Report No. 90922, Wang, Hubbs and Song 2002).** This report describes the effectiveness of using river bank filtration for the removal of DBP precursors and microbial contaminants as a function of design and operation variables. This document also provides general information for riverbank system design and operation.

6.3.7 Cost Estimation

Accurate cost estimation for facility upgrades requires a comprehensive database that consists of updated equipment and construction cost information. While engineering consultants and construction companies usually keep their proprietary cost estimation tools refined and updated with major cost indices, very few cost estimation tools for the drinking water industry are available to the general public. The cost estimation tools listed in this section represent the starting points for budgetary planning. Utility budgetary planning personnel should consult with the authors of these tools and the additional information sources listed at the end of this section for a more accurate and updated cost estimation.

- **Drinking Water Infrastructure Needs Survey: Modeling the Cost of Infrastructure (USEPA 2006c).** This document provides cost models for water sources (such as surface water intake, well development, and aquifer storage and recovery wells), various treatment processes, storage, transmission/distribution systems, pumping, and other (i.e., SCADA). The cost of rehabilitation is also provided along with new installation in some cases. These cost models were designed for estimating national infrastructure needs and are not applicable to estimating the costs of specific projects at individual water systems. The document is available at the following EPA web site: http://www.epa.gov/ogwdw/needssurvey/pdfs/2003/report_needssurvey_2003_costmodeling.pdf .

- **Water/Wastewater Costs, Windows Version 3.0, (Wesner 2000).** This computer software provides detailed capital and O&M costs of any combination of treatment processes based on the treatment processes and design criteria selected by the users. It should be noted that not all of the cost information of every treatment component were updated during the 2000 revision.

- **WTCost©, 2003.** This computer program is developed by the U.S. Bureau of Reclamation and I. Moch & Associates (sponsored by the American Membrane Technology Association, AMTA) for estimating membrane treatment plant costs. It allows the evaluation and comparison of water treatment processes that employ reverse osmosis/nanofiltration, electrodialysis, microfiltration/ultrafiltration, and ion exchange. Using flexible cost indices and adjustable inputs, WTCost includes costs equations for estimating different pre- and post-treatment unit operations such as gravity media filtration; coagulation and flocculation with powered activated carbon (PAC), granulated activated carbon (GAC), alum, ferric chloride, ferrous sulfate, or polyelectrolyte; disinfection by chlorine, monochloramine, ozone and UV; lime/soda softening; electrical, including energy recovery, and chemical consumption; and various intake and outfall infrastructures. Labor and supervision, membrane replacements, amortization rates, and tanks, piping, and instrumentation are also included in the cost model, permitting calculation of plant capital requirements, and operating and maintenance costs. Information on purchasing this tool can be found at the following Web site: http://www.membranes-amta.org/publications.html .

- **WaterCAD (Haestad Methods).** This commercial software can be used to design and analyze distribution systems, including pipelines, and pump stations. With the Cost Manager component, this program is capable of assessing the capital costs associated with the water distribution network including pumps, valves, and storage facilities, and recommends future improvements based on both hydraulic and financial impacts. Another cost function provided by this program is to estimate energy costs for constant speed and variable-speed pumps. This program can further examine the tradeoffs between energy costs and the capital costs required to improve pump efficiency.

- **Technologies and Costs for the Final Long Term 2 Enhanced Surface Water Treatment Rule and Final Stage 2 Disinfectants and Disinfection Byproducts Rule (USEPA 2005d)**. While this publication does not provide system-specific cost information, systems may use it to determine approximate and relative costs. The document is available at the following EPA website: http://www.epa.gov/safewater/disinfection/lt2/pdfs/costs_lt2-stage2_technologies.pdf

- **Technology and Cost Document for the Final Ground Water Rule. (USEPA 2006d).** Like the technologies and costs document for the final LT2ESWTR and Stage 2 DBPR, this cost document does not provide system-specific cost information. It can, however, be used to evaluate relative costs of different compliance technologies. The document is available at the following EPA website: http://www.epa.gov/safewater/disinfection/gwr/pdfs/support_gwr_cost-technologies.pdf.

- **Additional Resources for Cost Information**

    - Most recent cost information or cost curves of a specific technology are published in professional journals or conference proceedings;

    - Utilities from the same region that have conducted similar projects at similar scale in recent years;

    - Reputable equipment suppliers; and

  - Reputable engineering consultants.

6.3.8 Community Preferences

This section includes recently published AwwaRF research reports that provide utility survey data and practical guidance to assist water utilities in improving their customer communications, public perception, and public involvement of the water quality issues, regulatory compliance issues, and potential capital improvement projects.

- **Consumer Attitude Survey Update (AwwaRF Report No. 394, AwwaRF 2000).** This report discusses trends in public confidence and expectations, perceptions, and satisfaction. Also identified in this report are the driving factors behind these attitudes and trends and the impact of media on public confidence and customer satisfaction. The implications of these findings for measuring customer attitudes at the local utility level are also discussed.

- **Tools and Methods to Effectively Measure Customer Perceptions (AwwaRF Report No. 90856, Colbourne 2001).** This report evaluates available assessment tools and methods that measure customer perceptions and changes in their opinions toward drinking water utilities and utility services.

- **Best Practices for a Continually Improving Customer Responsive Organization (AwwaRF Report 90868, Olstein 2001).** This report provides case studies of five successful customer-driven water utilities that have used different approaches to achieving a continually improving customer-responsive organization. This document presents public input to the best practices, and a toolkit for utilities that includes a self-assessment questionnaire, a technology identification matrix, and benchmarking data.

- **Public Involvement . . . Making It Work (AwwaRF Report 90865, Nero et al. 2001).** In 1995, AwwaRF published the *Public Involvement Strategies: A Manager's Handbook* (AwwaRF 1995) to provide a framework for building consensus on difficult decisions. It presents a ten-step process to help water utility managers identify, understand, and plan public involvement and project implementation. This new report reduces the ten-step public involvement process to three essential steps, and provides a new handbook to guide utility managers through the public involvement process.

- **Public Involvement Strategies on the Web (AwwaRF 2003).** This web-based interactive tool was provided by AwwaRF in 2003 to expand the **AwwaRF Report 90865** (Nero et al. 2001) by offering public involvement case studies and interactive features on the internet. This interactive tool can be found at the following AwwaRF Web site: *http://www.awwarf.org/research/TopicsAndProjects/Resources/webTools/ch2m/default.html*.

- **Customer Attitudes, Behavior and the Impact of Communications Efforts (AwwaRF Report 90975, Tatham, Tatham and Mobley 2004).** This report provides guidelines on the following three areas that are critical to communication with customers: (1) determine whether or not communication can be used as a tool by water utilities to positively affect the attitudes and behaviors of residential water utility customers, (2) identify the types of information that should be communicated by water utilities to enhance customer satisfaction and the methods for communicating this information to customers, and (3) report on ways to inform customers about water quality issues and provide guidance on communication strategies. This report includes a CD-ROM that contains 18 Microsoft Word documents that illustrate the survey data for various demographic groups.

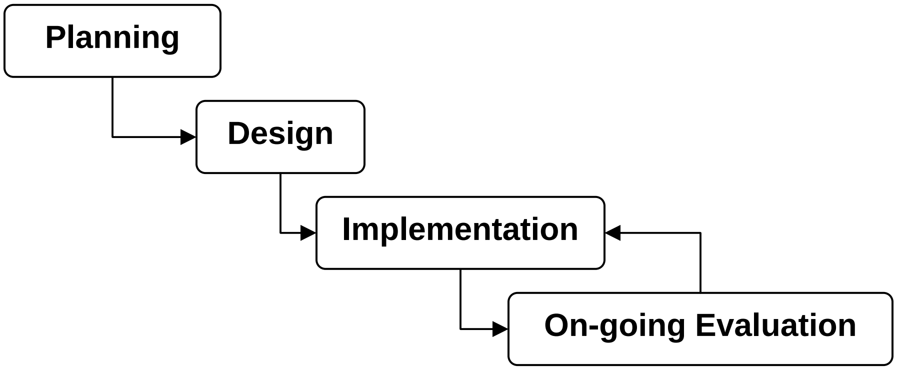
- **Effective Practices to Select, Acquire, and Implement a Utility CIS (AwwaRF Report 91071, Rettie et al. 2005).** This report provides guidance to utilities as they select, acquire, and implement a customer information system (CIS). Guidelines provided in this document focus on four areas: (1) characterizing the current status of water utilities regarding CIS solutions, (2) identifying and documenting critical success factors (and barriers to success) related to CIS implementations, (3) documenting successful CIS implementations and associated practices, and (4) providing a CIS projects roadmap for utilities.

- **Strategic Communication Planning: A Guide for Water Utilities (AwwaRF Report 91106, Mobley et al. 2006).** This report discusses the role of strategic communication planning in the overall performance and success of drinking water utilities. It establishes the link between high trust and credibility and the ability to communicate effectively. It provides a guidebook that integrates key findings from past research and this project to help drinking water utilities develop strategic communication plans.

6.4 Basic Approach for Implementing Regulatory Compliance Projects

The implementation of a project to accomplish regulatory compliance involves several stages, including planning, design, implementation, and on-going evaluation. Exhibit 6.2 illustrates how the tools discussed in this chapter can be used to accomplish these various project implementation stages.

In the planning stage, the project objective(s) should be defined and the data needs for meeting these objectives should be identified. In addition, the project team should seek input from all interested parties to confirm that the project has the correct focus and direction. The planning process typically includes an evaluation and comparison of various compliance options based on cost, treatment performance and other system-specific factors such as customer preferences.



Once a compliance option has been selected, the design stage is initiated to develop specific design criteria such as chemical dosage rates, equipment sizing, and plans for integrating new treatment processes with existing facilities. Further testing may be warranted during the design stage to establish design and operating criteria under expected treatment conditions.

Exhibit 6.2 Application of Information Gathering Tools at Various Project Implementation Stages

Tool Type	Planning	Design	Implementation	On-going Evaluation
Water quality monitoring	X		X	X
Hydraulic and water quality modeling for distribution systems	X		X	
Desktop evaluations	X			
Bench-scale testing	X	X	X	
Pilot testing	X	X		
Full-scale applications	X	X	X	
Cost estimation	X			X
Community preferences	X		X	X

Project implementation is the process of carrying out the project as designed and may involve site and building construction, equipment installation, and start-up operations. Water quality monitoring activities during this stage may focus on possible construction impacts to finished water quality and the local environment. Additional testing may be needed to address issues raised during start-up operations.

Once a project has been implemented, information should be gathered on an on-going basis to further optimize system operation, finished water quality, and O&M costs. Customer feedback is important at this stage to assure that the project has not caused unforeseen secondary impacts to water quality or customer service. Water quality monitoring may be intensive when new facilities are first put into service.

The approach used by Owenton Water Works and Kentucky American Tri-Village in solving their simultaneous compliance issue (as described in Case Study # 1 in Appendix B) is summarized as an example. Rather than switching to a higher quality source of supply, the water systems decided to take a less expensive approach by changing chlorination practices at the existing treatment facility to reduce TTHM. The approach included the following specific steps:

Planning

- Identified primary objective (reducing TTHM);
- Collected existing water quality data from both systems to define causative factors for elevated DBPs; and
- Considered costs of different compliance options (developing new source vs. modifying existing treatment).

Design

- Collected profiles of TOC removal, TTHM formation, and disinfection through the plant and distribution system;
- Conducted tracer studies to assess in-plant disinfection contact time; and
- Developed design drawings and specifications for new chlorine feed equipment.

Implementation

- Initiated enhanced coagulation at lower pH;
- Optimized potassium permanganate feed to raw water to control source water manganese;
- Revised operational guidelines to increase hydraulic retention time in plant clearwell;

- Moved chorination point; and
- Optimized chlorine dosage rates at distribution system booster stations.

On-going Evaluation

- Evaluated results of enhanced coagulation process change;
- Evaluated results of potassium permanganate feed changes; and
- Continued to conduct special distribution system water quality monitoring.

7 References

The references in this chapter have been organized as follows under the following headings in Section 7.1, with a complete alphabetical list in Section 7.2:

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7.1 References Organized by Topic

7.1.1 General

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Appendix A

Summary of Pertinent Drinking Water Regulations

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Appendix A
Summary of Pertinent Drinking Water Regulations

This appendix contains fact sheets and quick reference guides for the major rules discussed in this guidance manual. The fact sheets and quick reference guides are brief summaries of the major requirements of the rules. More detailed information on rule requirements and guidance can be found on EPA's Web site at http://www.epa.gov/safewater. The following is a list of fact sheets and quick reference guides that are included in this appendix and the order in which they appear:

Rule	***Date of Promulgation***	***Contaminant of Concern***	***Rule Summary Information Available from EPA***
Ground Water Rule (GWR)	November 2006	Source Water Microbial Pathogens	Fact Sheet
Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR)	January 2006	Source Water Microbial Pathogens	Fact Sheet
Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2 DBPR)	January 2006	Disinfection Byproducts	Fact Sheet
Arsenic and Clarifications to Compliance and New Source Monitoring Rule	January 2001	Arsenic	Quick Reference Guide
Lead and Copper Rule (LCR)	June 1991	Lead and Copper	Quick Reference Guide
LCR Clarification of Requirements for Collecting Samples and Calculating Compliance	March 2004	Lead and Copper	Fact Sheet
Total Coliform Rule (TCR)	June 1989	Distribution System Microbial Pathogens	Quick Reference Guide
Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 D/DBPR)	December 1998	Disinfectants and Disinfection Byproducts	Quick Reference Guide
Interim Enhanced Surface Water Treatment Rule (IESWTR)	December 1998	Source Water Microbial Pathogens	Quick Reference Guide
Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR)	January 2002	Source Water Microbial Pathogens	Quick Reference Guide
Filter Backwash Recycling Rule (FBRR)	June 2001	Filter Backwash (Microbial Pathogens)	Quick Reference Guide

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Final Ground Water Rule

Summary

The Environmental Protection Agency (EPA) promulgated the final Ground Water Rule (GWR) in October 2006 to reduce the risk of exposure to fecal contamination that may be present in public water systems that use ground water sources. EPA proposed the GWR on May 10, 2000 (65 *Federal Register* 30194). The rule establishes a risk-targeted strategy to identify ground water systems that are at high risk for fecal contamination. The GWR also specifies when corrective action (which may include disinfection) is required to protect consumers who receive water from ground water systems from bacteria and viruses.

Background

The 1996 Amendments to the Safe Drinking Water Act required EPA to develop regulations that require disinfection of ground water systems “as necessary” to protect the public health (section 1412(b)(8)).

Ground water occurrence studies and recent outbreak data show that pathogenic viruses and bacteria can occur in public water systems that use ground water and that people may become ill due to exposure to contaminated ground water.

Most cases of waterborne disease are characterized by gastrointestinal symptoms (e.g., diarrhea, vomiting, etc.) that are frequently self-limiting in healthy individuals and rarely require medical treatment. However, these same symptoms are much more serious and can be fatal for persons in sensitive subpopulations (such as young children, the elderly, and persons with compromised immune systems).

Viral and bacterial pathogens are present in human and animal feces, which can, in turn, contaminate drinking water. Fecal contamination can reach ground water sources, including drinking water wells, from failed septic systems, leaking sewer lines, and by passing through the soil and large cracks in the ground. Fecal contamination from the surface may also get into a drinking water well along its casing or through cracks if the well is not properly constructed, protected, or maintained.

EPA does not believe all ground water systems are fecally contaminated; data indicate that only a small percentage of ground water systems are fecally contaminated. However, the severity of health impacts and the number of people potentially exposed to microbial pathogens in ground water indicate that a regulatory response is warranted.

About this Regulation

The GWR applies to more than 147, 000 public water systems that use ground water (as of 2003). The rule also applies to any system that mixes surface and ground water if the ground water is added directly to the distribution system and provided to consumers without treatment equivalent to surface water treatment. In total, these systems provide drinking water to more than 100 million consumers.

***Final Requirements**:* The rule addresses risks through a risk-targeting approach that relies on four major components:

1. Periodic sanitary surveys of ground water systems that require the evaluation of eight critical elements and the identification of significant deficiencies (e.g., a well located near a leaking septic system). States must complete the initial survey by December 31, 2012 for most community water systems (CWSs) and by December 31, 2014 for CWSs with outstanding performance and for all non-community water systems.

2. Source water monitoring to test for the presence of *E. coli*, enterococci, or coliphage in the sample. There are two monitoring provisions:
   -*Triggered monitoring* for systems that do not already provide treatment that achieves at least 99.99 percent (4-log) inactivation or removal of viruses and that have a total coliform-positive routine sample under Total Coliform Rule sampling in the distribution system.
   -*Assessment monitoring*- As a complement to triggered monitoring, a State has the option to require systems, at any time, to conduct source water assessment monitoring to help identify high risk systems.

3. Corrective actions required for any system with a significant deficiency or source water fecal contamination. The system must implement one or more of the following correction action options:
   -correct all significant deficiencies,
   -eliminate the source of contamination,
   -provide an alternate source of water, or
   -provide treatment which reliably achieves 99.99 percent (4-log) inactivation or removal of viruses.

4. Compliance monitoring to ensure that treatment technology installed to treat drinking water reliably achieves at least 99.99 percent (4-log) inactivation or removal of viruses.

Environmental and Public Health Benefits

The GWR will reduce public health risk from contaminated ground water drinking water sources, especially in high-risk or high-priority systems. The GWR is estimated to reduce the average number of waterborne viral (rotovirus and echovirus) illnesses by nearly 42,000 illnesses each year from the current baseline estimate of approximately 185,000 (a 23 percent reduction in total illnesses). In addition, nonquantified benefits from the rule resulting in illness reduction from other viruses and bacteria are expected to be significant.

Cost of the Regulation

The GWR will result in increased costs to public water systems and States. The mean annualized present value national compliance costs of the final GWR are estimated to be approximately $62 million (using three percent discount rate). Public water systems will bear the majority of costs. The annual household costs for community water systems (including those that do not add treatment) range from $0.21 to $16.54. Annual household costs for the subset of systems that undertake corrective actions range from $0.45 to $52.38, with 90 percent having household cost increases of no more than $3.20.

How to Get Additional Information

For general information on the GWR, please contact the Safe Drinking Water Hotline, at (800) 426-4791. The Safe Drinking Water Hotline is open Monday through Friday, excluding Federal holidays, from 10 a.m. to 4 p.m., Eastern time. For copies of the Federal Register notice of the final regulation, visit the EPA Safewater Web site, http://www.epa.gov/safewater/disinfection/gwr.

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Fact Sheet - Long Term 2 Enhanced Surface Water Treatment Rule

In the past 30 years, the Safe Drinking Water Act (SDWA) has been highly effective in protecting public health and has also evolved to respond to new and emerging threats to safe drinking water. Disinfection of drinking water is one of the major public health advances in the 20th century. One hundred years ago, typhoid and cholera epidemics were common through American cities; disinfection was a major factor in reducing these epidemics.

In the past 15 years, we have learned that there are specific microbial pathogens, such as *Cryptosporidium*, which can cause illness, and are highly resistant to traditional disinfection practices. We also know that the disinfectants themselves can react with naturally-occurring materials in the water to form byproducts, which may pose health risks.

Amendments to the SDWA in 1996 require EPA to develop rules to balance the risks between microbial pathogens and disinfection byproducts (DBPs). The Stage 1 Disinfectants and Disinfection Byproducts Rule and Interim Enhanced Surface Water Treatment Rule, promulgated in December 1998, were the first phase in a rulemaking strategy required by Congress as part of the 1996 Amendments to the Safe Drinking Water Act.

The Long Term 2 Enhanced Surface Water Treatment Rule builds upon earlier rules to address higher risk public water systems for protection measures beyond those required for existing regulations.

The Long Term 2 Enhanced Surface Water Treatment Rule and the Stage 2 Disinfection Byproduct Rule are the second phase of rules required by Congress. These rules strengthen protection against microbial contaminants, especially *Cryptosporidium*, and at the same time, reduce potential health risks of DBPs.

Questions and Answers

What is the LT2ESWTR?

The purpose of Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) is to reduce illness linked with the contaminant *Cryptosporidium* and other pathogenic microorganisms in drinking water. The LT2ESWTR will supplement existing regulations by targeting additional *Cryptosporidium* treatment requirements to higher risk systems. This rule also contains provisions to reduce risks from uncovered finished water reservoirs and provisions to ensure that systems maintain microbial protection when they take steps to decrease the formation of disinfection byproducts that result from chemical water treatment.

Current regulations require filtered water systems to reduce source water *Cryptosporidium* levels by 2-log (99 percent). Recent data on *Cryptosporidium* infectivity and occurrence indicate that this treatment requirement is sufficient for most systems, but additional treatment is necessary for certain higher risk systems. These higher risk systems include filtered water systems with high levels of *Cryptosporidium* in their water sources and all unfiltered water systems, which do not treat for *Cryptosporidium*.

The LT2ESWTR is being promulgated simultaneously with the Stage 2 Disinfection Byproduct Rule to address concerns about risk tradeoffs between pathogens and DBPs.

What are the health risks of Cryptosporidium?

Cryptosporidium is a significant concern in drinking water because it contaminates most surface waters used as drinking water sources, it is resistant to chlorine and other disinfectants, and it has caused waterborne disease outbreaks. Consuming water with *Cryptosporidium* can cause gastrointestinal illness, which may be severe and sometimes fatal for people with weakened immune systems (which may include infants, the elderly, and people who have AIDS).

Who must comply with this rule?

This regulation will apply to all public water systems that use surface water or ground water under the direct influence of surface water.

What does the rule require?

Monitoring*:* Under the LT2ESWTR, systems will monitor their water sources to determine treatment requirements. This monitoring includes an initial two years of monthly sampling for *Cryptosporidium*. To reduce monitoring costs, small filtered water systems will first monitor for *E. coli*—a bacterium which is less expensive to analyze than *Cryptosporidium*—and will monitor for *Cryptosporidium* only if their *E. coli* results exceed specified concentration levels.

Monitoring starting dates are staggered by system size, with smaller systems beginning monitoring after larger systems. Systems must conduct a second round of monitoring six years after completing the initial round to determine if source water conditions have changed significantly. Systems may use (grandfather) previously collected data in lieu of conducting new monitoring, and systems are not required to monitor if they provide the maximum level of treatment required under the rule.

Cryptosporidium* treatment*: Filtered water systems will be classified in one of four treatment categories (bins) based on their monitoring results. The majority of systems will be classified in the lowest treatment bin, which carries no additional treatment requirements. Systems classified in higher treatment bins must provide 90 to 99.7 percent (1.0 to 2.5-log) additional treatment for *Cryptosporidium*. Systems will select from a wide range of treatment and management strategies in the "microbial toolbox" to meet their additional treatment requirements. All unfiltered water systems must provide at least 99 or 99.9 percent (2 or 3-log) inactivation of *Cryptosporidium*, depending on the results of their monitoring. These *Cryptosporidium* treatment requirements reflect consensus recommendations of the Stage 2 Microbial and Disinfection Byproducts Federal Advisory Committee.

Other requirements: Systems that store treated water in open reservoirs must either cover the reservoir or treat the reservoir discharge to inactivate 4-log virus, 3-log *Giardia lamblia*, and 2-log *Cryptosporidium*. These requirements are necessary to protect against the contamination of water that occurs in open reservoirs. In addition, systems must review their current level of microbial treatment before making a significant change in their disinfection practice. This review will assist systems in maintaining protection against microbial pathogens as they take steps to reduce the formation of disinfection byproducts under the Stage 2 Disinfection Byproducts Rule, which EPA is finalizing along with the LT2ESWTR.

What are the benefits of the rule?

The LT2ESWTR will improve the control of *Cryptosporidium* and other microbiological pathogens in drinking water water systems with the highest risk levels. EPA estimates that full compliance with the LT2ESWTR will reduce the incidence of cryptosporidiosis - the gastrointestinal illness caused by ingestion of *Cryptosporidium* - by 89,000 to 1,459,000 cases per year, with an associated reduction of 20 to 314 premature deaths. The monetized benefits associated with these reductions ranges from $253 million to $1.445 billion per year. The additional *Cryptosporidium* treatment requirements of the LT2ESWTR will also reduce exposure to other microbial pathogens, such as *Giardia*, that co-occur with *Cryptosporidium*. Additional protection from microbial pathogens will come from provisions in this rule for reviewing disinfection practices and for covering or treating uncovered finished water reservoirs, though EPA has not quantified these benefits.

What are the costs of the rule?

The LT2ESWTR will result in increased costs to public water systems and states. The average annualized present value costs of the LT2ESWTR are estimated to range from $92 to $133 million (using a three percent discount rate). Public water systems will bear approximately 99 percent of this total cost, with states incurring the remaining 1 percent. The average annual household cost is estimated to be $1.67 to $2.59 per year, with 96 to 98 percent of households experiencing annual costs of less than $12 per year.

What technical information will be available on the rule?

The following guidance documents will be available:

- Source Water Monitoring Guidance
- Microbial Laboratory Guidance
- Small Entity Compliance Guidance
- Microbial Toolbox Guidance Manual
- Ultraviolet Disinfection Guidance Manual
- Membrane Filtration Guidance Manual
- Simultaneous Compliance Guidance Manual
- Low-pressure Membrane Filtration for Pathogen Removal: Application, Implementation, and Regulatory Issues

Where can I find more information about this notice and the LT2ESWTR?

For general information on the LT2ESWTR, contact the Safe Drinking Water Hotline at (800) 426-4791. The Safe Drinking Water Hotline is open Monday through Friday, excluding legal holidays, from 10:00 a.m. to 4:00 p.m., Eastern time. For copies of the Federal Register notice of the regulation or technical fact sheets, visit the EPA Safewater website at http://www.epa.gov/safewater/disinfection/lt2. For technical inquiries, email stage2mdbp@epa.gov.

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Fact Sheet: Stage 2 Disinfectants and Disinfection Byproducts Rule

In the past 30 years, the Safe Drinking Water Act (SDWA) has been highly effective in protecting public health and has also evolved to respond to new and emerging threats to safe drinking water. Disinfection of drinking water is one of the major public health advances in the 20th century. One hundred years ago, typhoid and cholera epidemics were common through American cities; disinfection was a major factor in reducing these epidemics.

However, the disinfectants themselves can react with naturally-occurring materials in the water to form byproducts, which may pose health risks. In addition, in the past 10 years, we have learned that there are specific microbial pathogens, such as *Cryptosporidium*, which can cause illness, and are highly resistant to traditional disinfection practices.

Amendments to the SDWA in 1996 require EPA to develop rules to balance the risks between microbial pathogens and disinfection byproducts (DBPs). The Stage 1 Disinfectants and Disinfection Byproducts Rule and Interim Enhanced Surface Water Treatment Rule, promulgated in December 1998, were the first phase in a rulemaking strategy required by Congress as part of the 1996 Amendments to the Safe Drinking Water Act.

The Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2 DBPR) builds upon the Stage 1 DBPR to address higher risk public water systems for protection measures beyond those required for existing regulations.

The Stage 2 DBPR and the Long Term 2 Enhanced Surface Water Treatment Rule are the second phase of rules required by Congress. These rules strengthen protection against microbial contaminants, especially *Cryptosporidium*, and at the same time, reduce potential health risks of DBPs.

Questions and Answers

What is the Stage 2 DBPR?

The Stage 2 Disinfection Byproducts Rule will reduce potential cancer and reproductive and developmental health risks from disinfection byproducts (DBPs) in drinking water, which form when disinfectants are used to control microbial pathogens. Over 260 million individuals are exposed to DBPs.

This final rule strengthens public health protection for customers by tightening compliance monitoring requirements for two groups of DBPs, trihalomethanes (TTHM) and haloacetic acids (HAA5). The rule targets systems with the greatest risk and builds incrementally on existing rules. This regulation will reduce DBP exposure and related potential health risks and provide more equitable public health protection.

The Stage 2 DBPR is being promulgated simultaneously with the Long Term 2 Enhanced Surface Water Treatment Rule to address concerns about risk tradeoffs between pathogens and DBPs.

What does the rule require?

Under the Stage 2 DBPR, systems will conduct an evaluation of their distribution systems, known as an Initial Distribution System Evaluation (IDSE), to identify the locations with high disinfection byproduct concentrations. These locations will then be used by the systems as the sampling sites for Stage 2 DBPR compliance monitoring.

Compliance with the maximum contaminant levels for two groups of disinfection byproducts (TTHM and HAA5) will be calculated for each monitoring location in the distribution system. This approach, referred to as the locational running annual average (LRAA), differs from current requirements, which determine compliance by calculating the running annual average of samples from all monitoring locations across the system.

The Stage 2 DBPR also requires each system to determine if they have exceeded an operational evaluation level, which is identified using their compliance monitoring results. The operational evaluation level provides an early warning of possible future MCL violations, which allows the system to take proactive steps to remain in compliance. A system that exceeds an operational evaluation level is required to review their operational practices and submit a report to their state that identifies actions that may be taken to mitigate future high DBP levels, particularly those that may jeopardize their compliance with the DBP MCLs.

Who must comply with the rule?

Entities potentially regulated by the Stage 2 DBPR are community and nontransient noncommunity water systems that produce and/or deliver water that is treated with a primary or residual disinfectant other than ultraviolet light.

A community water system (CWS) is a public water system that serves year-round residents of a community, subdivision, or mobile home park that has at least 15 service connections or an average of at least 25 residents.

A nontransient noncommunity water system (NTNCWS) is a water system that serves at least 25 of the same people more than six months of the year, but not as primary residence, such as schools, businesses, and day care facilities.

What are disinfection byproducts (DBPs)?

Disinfectants are an essential element of drinking water treatment because of the barrier they provide against waterborne disease-causing microorganisms. Disinfection byproducts (DBPs) form when disinfectants used to treat drinking water react with naturally occurring materials in the water (e.g., decomposing plant material).

Total trihalomethanes (TTHM - chloroform, bromoform, bromodichloromethane, and dibromochloromethane) and haloacetic acids (HAA5 - monochloro-, dichloro-, trichloro-, monobromo-, dibromo-) are widely occurring classes of DBPs formed during disinfection with chlorine and chloramine. The amount of trihalomethanes and haloacetic acids in drinking water can change from day to day, depending on the season, water temperature, amount of disinfectant added, the amount of plant material in the water, and a variety of other factors.

Are THMs and HAAs the only disinfection byproducts?

No. The four THMs (TTHM) and five HAAs (HAA5) measured and regulated in the Stage 2 DBPR act as indicators for DBP occurrence. There are many other known DBPs, in addition to the possibility of unidentified DBPs present in disinfected water. THMs and HAAs typically occur at higher levels than other known and unknown DBPs. The presence of TTHM and HAA5 is representative of the occurrence of many other chlorination DBPs; thus, a reduction in the TTHM and HAA5 generally indicates a reduction of DBPs from chlorination.

What are the costs and benefits of the rule?

Quantified benefits estimates for the Stage 2 DBPR are based on reductions in fatal and non-fatal bladder cancer cases. EPA has projected that the rule will prevent approximately 280 bladder cancer cases per year. Of these cases, 26% are estimated to be fatal. Based on bladder cancer alone, the rule is estimated to provide annualized monetized benefit of $763 million to $1.5 billion.

The rule applies to approximately 75,000 systems; a small subset of these (about 4%) will be required to make treatment changes. The mean cost of the rule is $79 million annually. Annual household cost increases in the subset of plants adding treatment are estimated at an average of $5.53, with 95 percent paying less than $22.40.

What are the compliance deadlines?

Compliance deadlines are based on the sizes of the public water systems (PWSs). Wholesale and consecutive systems of any size must comply with the requirements of the Stage 2 DBPR on the same schedule as required for the largest system in the combined distribution system (defined as the interconnected distribution system consisting of wholesale systems and consecutive systems that receive finished water). Compliance activities are outlined in the following table.

PUBLIC WATER SYSTEMS	**ACTIONS**			
	Submit IDSE monitoring plan, system specific study plan, or 40/30 certification	**Complete an initial distribution system evaluation (IDSE)**	**Submit IDSE Report**	**Begin subpart V (Stage 2) compliance monitoring**
CWSs and NTNCWSs serving at least 100,000	October 1, 2006	September 30, 2008	January 1, 2009	April 1, 2012
CWSs and NTNCWSs serving 50,000 - 99,999	April 1, 2007	March 31, 2009	July 1, 2009	October 1, 2012
CWSs and NTNCWSs serving 10,000 - 49,999	October 1, 2007	September 30, 2009	January 1, 2010	October 1, 2013
CWSs serving fewer than 10,000	April 1, 2008	March 31, 2010	July 1, 2010	October 1, 2013
NTNCWSs serving fewer than 10,000	NA	NA	NA	October 1, 2013

*States may grant up to an additional two years for systems making capital improvements.

What technical information will be available on the rule?

The following Guidance Documents will be available:

- Initial Distribution System Evaluation (IDSE) Guidance Manual
- Operational Evaluation Guidance Manual
- Consecutive Systems Guidance Manual
- Small Systems (SBREFA) Guidance Manual
- Simultaneous Compliance Guidance Manual

Where can I find more information about this notice and the Stage 2 DBPR?

For general information on the rule, please visit the EPA Safewater website at http://www.epa.gov/safewater/disinfection/stage2 or contact the Safe Drinking Water Hotline at 1-800-426-4791. The Safe Drinking Water Hotline is open Monday through Friday, excluding legal holidays, from 10:00 a.m. to 4:00 p.m., Eastern Time. For technical inquiries, email stage2mdbp@epa.gov.

United States
Environmental Protection
Agency

Office of Water
(4606)

EPA 816-F-01-004
January 2001

Arsenic and Clarifications to Compliance and New Source Monitoring Rule: A Quick Reference Guide

Overview of the Rule

Title	**Arsenic and Clarifications to Compliance and New Source Monitoring Rule 66 FR 6976 (January 22, 2001)**
Purpose	**To improve public health by reducing exposure to arsenic in drinking water.**
General Description	**Changes the arsenic MCL from 50 µg/L to 10 µg/L; Sets arsenic MCLG at 0; Requires monitoring for new systems and new drinking water sources; Clarifies the procedures for determining compliance with the MCLs for IOCs, SOCs, and VOCs.**
Utilities Covered	**All community water systems (CWSs) and nontransient, noncommunity water systems (NTNCWSs) must comply with the arsenic requirements. EPA estimates that 3,024 CWSs and 1,080 NTNCWSs will have to install treatment to comply with the revised MCL.**

Public Health Benefits

Implementation of the Arsenic Rule will result in . . .	• **Avoidance of 16 to 26 non-fatal bladder and lung cancers per year.** • **Avoidance of 21 to 30 fatal bladder and lung cancers per year.** • **Reduction in the frequency of non-carcinogenic diseases.**

Critical Deadlines & Requirements

Consumer Confidence Report Requirements *

Report Due	*Report Requirements*
July 1, 2001	**For the report covering calendar year 2000, systems that detect arsenic between 25 µg/L and 50 µg/L must include an educational statement in the consumer confidence reports (CCRs).**
July 1, 2002 and beyond	**For reports covering calendar years 2001 and beyond, systems that detect arsenic between 5 µg/L and 10 µg/L must include an educational statement in the CCRs.**
July 1, 2002 - July 1, 2006	**For reports covering calendar years 2001 to 2005, systems that detect arsenic between 10 µg/L and 50 µg/L must include a health effects statement in their CCRs.**
July 1, 2007 and beyond	**For reports covering calendar year 2006 and beyond, systems that are in violation of the arsenic MLC (10 µg/L) must include a health effects statement in their CCRs.**

For Drinking Water Systems

Jan. 22, 2004	**All *NEW* systems/sources must collect initial monitoring samples for all IOCs, SOCs, and VOCs within a period and frequency determined by the State.**
Jan. 1, 2005	**When allowed by the State, systems may grandfather data collected after this date.**
Jan. 23, 2006	**The new arsenic MCL of 10 µg/L becomes effective. All systems must begin monitoring or when allowed by the State, submit data that meets grandfathering requirements.**
Dec. 31, 2006	**Surface water systems must complete initial monitoring or have a State approved waiver.**
Dec. 31, 2007	**Ground water systems must complete initial monitoring or have a State approved waiver.**

For States

Spring 2001	**EPA meets and works with States to explain new rules and requirements and to initiate adoption and implementation activities.**
Jan. 22, 2003	**State primacy revision applications due.**
Jan. 22, 2005	**State primacy revision applications due from States that received 2-year extensions.**

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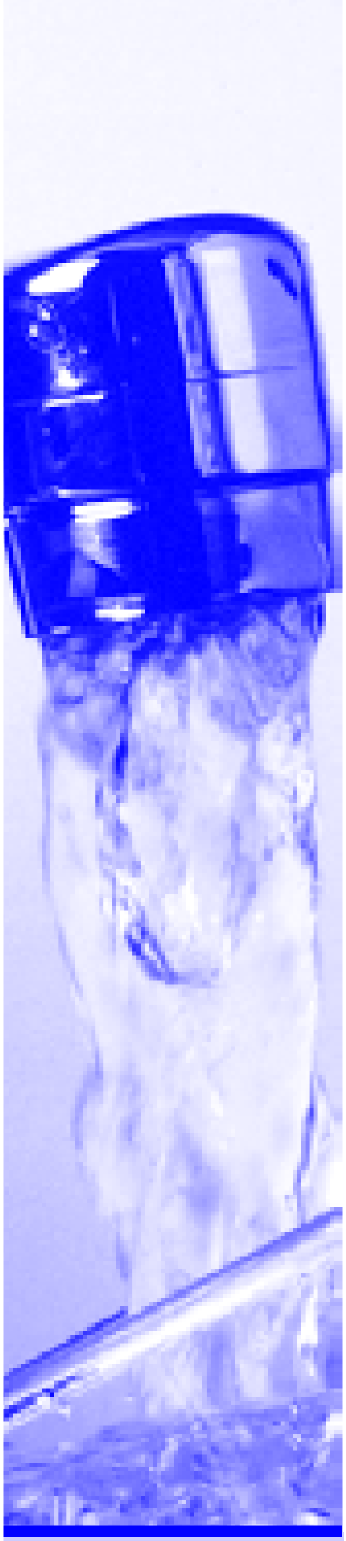
* For required educational and health effects statements, please see 40 CFR 141.154.



For additional information on the Arsenic Rule

Call the Safe Drinking Water Hotline at 1-800-426-4791; visit the EPA Web site at www.epa.gov/safewater; or contact your State drinking water representative. EPA will provide arsenic training over the next year.

Compliance Determination (IOCs, VOCs, and SOCs)

1. **Calculate compliance based on a running annual average at each sampling point.**
2. **Systems will not be in violation until 1 year of quarterly samples have been collected (unless fewer samples would cause the running annual average to be exceeded.)**
3. **If a system does not collect all required samples, compliance will be based on the running annual average of the samples collected.**

Monitoring Requirements for Total Arsenic (1)

Initial Monitoring

One sample after the effective date of the MCL (January 23, 2006). Surface water systems must take annual samples. Ground water systems must take one sample between 2005 and 2007.

Reduced Monitoring

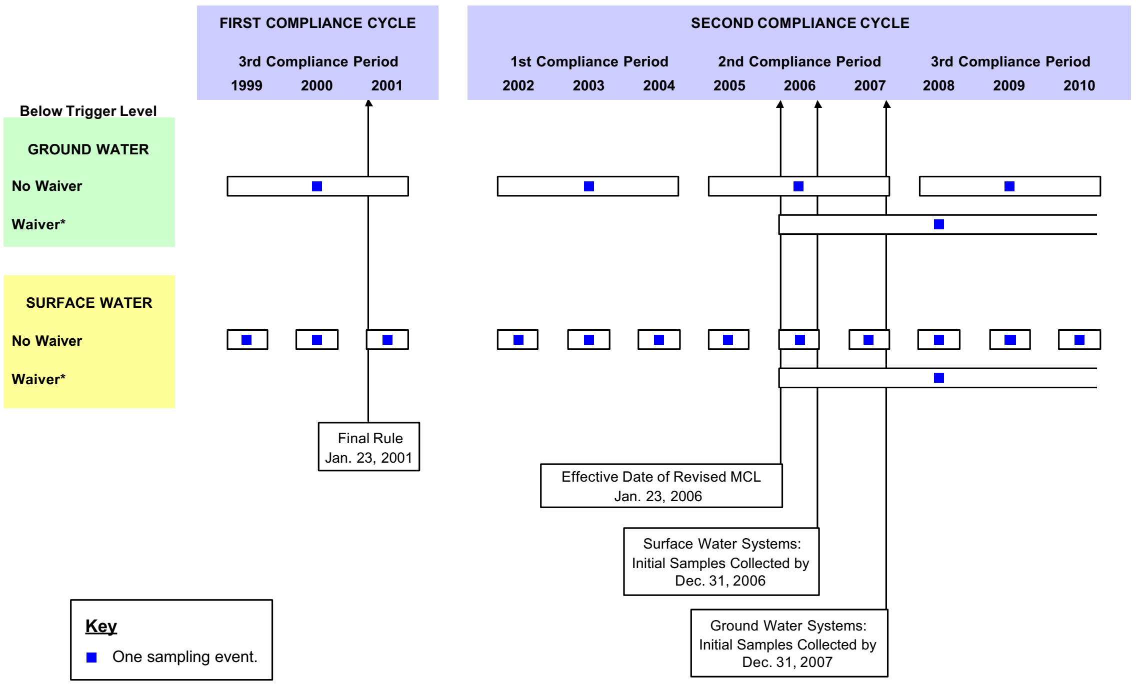
If the initial monitoring result for arsenic is less than the MCL . . .	**Ground water systems must collect one sample every 3 years. Surface water systems must collect annual samples.**

Increased Monitoring

A system with a sampling point result above the MCL must collect quarterly samples at that sampling point, until the system is reliably and consistently below the MCL.

(1) All samples must be collected at each entry point to the distribution system, unless otherwise specified by the State.

Applicability of the Standardized Monitoring Framework to Arsenic



*Waivers are not permitted under the current arsenic requirements. States may issue 9 year monitoring waivers under the revised final arsenic rule. To be eligible for a waiver, surface water systems must have monitored annually for at least 3 years. Ground water systems must conduct a minimum of 3 rounds of monitoring with detection limits below 10 µg/L.

EPA United States Environmental Protection Agency

Lead and Copper Rule: A Quick Reference Guide

Overview of the Rule

Title	**Lead and Copper Rule (LCR)[1], 56 FR 26460 - 26564, June 7, 1991**
Purpose	**Protect public health by minimizing lead (Pb) and copper (Cu) levels in drinking water, primarily by reducing water corrosivity. Pb and Cu enter drinking water mainly from corrosion of Pb and Cu containing plumbing materials.**
General Description	**Establishes action level (AL) of 0.015 mg/L for Pb and 1.3 mg/L for Cu based on 90th percentile level of tap water samples. An AL exceedance is not a violation but can trigger other requirements that include water quality parameter (WQP) monitoring, corrosion control treatment (CCT), source water monitoring/treatment, public education, and lead service line replacement (LSLR).**
Utilities Covered	**All community water systems (CWSs) and non-transient, non-community water systems (NTNCWSs) are subject to the LCR requirements.**

Public Health Benefits

Implementation of the LCR has resulted in . . .	▸ **Reduction in risk of exposure to Pb that can cause damage to brain, red blood cells, and kidneys, especially for young children and pregnant women.** ▸ **Reduction in risk of exposure to Cu that can cause stomach and intestinal distress, liver or kidney damage, and complications of Wilson's disease in genetically predisposed people.**

Lead and Copper Tap Sampling Requirements

- **First draw samples must be collected by all CWSs & NTNCWSs at cold water taps in homes/buildings that are at high risk of Pb/Cu contamination as identified in 40 CFR 141.86(a).**
- **Number of sample sites is based on system size (see Table 1).**
- **Systems must conduct monitoring every 6 months unless they qualify for reduced monitoring (see Table 2).**

Table 1: Pb and Cu Tap and WQP Tap Monitoring

Size Category	System Size	Number of Pb/Cu Tap Sample Sites		Number of WQP Tap Sampling Sites	
		Standard	Reduced	Standard	Reduced
Large	**> 100K**	100	50	25	10
	50,001-100K	60	30	10	7
Medium	**10,001 - 50K**	60	30	10	7
	3,301 - 10K	40	20	3	3
Small	**501 - 3,300**	20	10	2	2
	101 - 500	10	5	1	1
	≤ 100	5	5	1	1

Table 2: Criteria for Reduced Pb/Cu Tap Monitoring[a]

Can Monitor . . .	***If the System . . .***
Annually	1. Serves ≤ 50,000 and is ≤ both ALs for 2 consecutive 6-month monitoring periods; ***or***
	2. Meets Optimal Water Quality Parameter (OWQP) specifications for 2 consecutive 6-month monitoring periods.
Triennially	1. Serves ≤ 50,000 and is ≤ both ALs for 3 consecutive years of monitoring; ***or***
	2. Meets OWQP specifications for 3 consecutive years of monitoring; ***or***
	3. Has 90th percentile Pb levels ≤ 0.005 mg/L & 90th percentile Cu level ≤ 0.65 mg/L for 2 consecutive 6-month periods (*i.e*, accelerated reduced Pb/Cu tap monitoring), ***or***
	4. Meets the 40 CFR 141.81(b)(3) criteria.
Once every 9 years	Serves ≤ 3,300 and meets monitoring waiver criteria found at 40 CFR 141.86(g).

[a] Samples are collected at reduced number of sites (see Table 1 above).

Treatment Technique and Sampling Requirements

CORROSION CONTROL TREATMENT INSTALLATION: All large systems (except systems that meet the requirements of 40 CFR 141.81(b)(2) or (3)) must install CCT. Medium and small systems that exceed either AL must install CCT.

WATER QUALITY PARAMETER MONITORING: All large systems are required to do WQP monitoring. Medium and small systems that exceed either AL are required to do WQP monitoring.

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[1] The June 1991 LCR was revised with the following Technical Amendments:
56 FR 32112, July 15, 1991;
57 FR 28785, June 29, 1992;
59 FR 33860, June 30, 1994;
and the LCR Minor Revisions
65 FR 1950, January 12, 2000.

Treatment Technique and Sampling Requirements if the AL is Exceeded

❶ Water Quality Parameter (WQP) Monitoring

- All systems serving > 50,000 people, and those systems serving ≤ 50,000 people if 90th percentile tap level > either AL, must take WQP samples during the same monitoring periods as Pb/Cu tap sample.
- Used to determine water corrosivity, and if needed, to help identify type of CCT to be installed and how CCT should be operated (*i.e.*, establishes OWQP levels).
- WQPs include: pH, alkalinity, calcium, conductivity (initial WQP monitoring only), orthophosphate (if phosphate-based inhibitor is used); silica (if silicate-based inhibitor is used), and temperature (initial WQP monitoring only).
- Samples are collected within distribution system (*i.e.*, WQP tap samples), with number of sites based on system size (see Table 1), and at each entry point to distribution system (EPTDS).
- Systems installing CCT, must conduct follow-up monitoring for 2 consecutive 6-month periods – WQP tap monitoring is conducted semi-annually; EPTDS monitoring increases to every two weeks.
- After follow-up monitoring, State sets ranges of values for the OWQPs.
- Reduced WQP tap monitoring is available for systems in compliance with OWQPs; *Reduced monitoring does not apply to EPTDS monitoring.*
- For systems ≤ 50,000, WQP monitoring is not required whenever 90th percentile tap levels are ≤ both ALs.

❷ Public Education (PE)

- Only required if Pb AL is exceeded *(no public education is required if only Cu AL exceeded)*.
- Informs Public Water System's (PWS) customers about health effects, sources, and what can be done to reduce exposure.
- Includes billing inserts sent directly to customers, pamphlets or brochures distributed to hospitals & other locations that provide services to pregnant woman & children, and for some CWSs, newspaper notices and public service announcements (PSAs) submitted to TV/radio stations.
- System must begin delivering materials within 60 days of Pb AL exceedance and continue every 6 months for PSAs and annually for all other forms of delivery for as long as it exceeds Pb AL.
- Different delivery methods and mandatory language for CWSs & NTNCWSs.
- Can discontinue delivery whenever ≤ Pb AL; but must recommence if Pb AL subsequently exceeded.
- PE requirements are in addition to the Public Notification required in 40 CFR Subpart Q.

❸ Source Water Monitoring and Treatment

- All systems that exceed Pb or Cu AL must collect source water samples to determine contribution from source water to total tap water Pb/Cu levels and make a source water treatment (SOWT) recommendation within 6 months of the exceedance.
- One set of samples at each EPTDS is due within 6 months of first AL exceedance.
- If State requires SOWT; system has 24 months to install SOWT.
- After follow-up Pb/Cu tap and EPTDS monitoring, State sets maximum permissible levels for Pb & Cu in source.

❹ Corrosion Control Treatment

- Required for all large systems (except systems that meet the requirements of 40 CFR 141.81(b)(2) or (b)(3)) and medium/small systems that exceed either AL. The system shall recommend optimal CCT within 6 months.
- Corrosion control study required for large systems.
- If State requires study for medium or small systems, it must be completed within 18 months.
- Once State determines type of CCT to be installed, PWS has 24 months to install CCT.
- Systems installing CCT must conduct 2 consecutive 6-months of follow-up monitoring.
- After follow-up Pb/Cu tap & WQP monitoring, State sets OWQPs.
- Small & medium systems can stop CCT steps if ≤ both ALs for 2 consecutive 6-month monitoring periods.

If the system continues to exceed the AL after installing CCT and/or SOWT...

❺ Lead Service Line (LSL) Monitoring

- Two types of sampling associated with LSL replacement (LSLR):
  - *Optional* - Monitoring from LSL to determine need to replace line. If all Pb samples from line ≤ 0.015 mg/L then LSL does not need to be replaced and counts as replaced line.
  - *Required* - Monitoring if entire LSL is ***not*** replaced to determine impact from "partial" LSLR. Sample is collected that is representative of water in service line that is partially replaced.
- Monitoring only applies to system subject to LSLR.

❻ Lead Service Line Replacement

- System must replace LSLs that contribute more than 0.015 mg/L to tap water levels.
- Must replace 7% of LSL per year; State can require accelerated schedule.
- If only a portion of a LSL is replaced, PWS must:
  - Notify customers at least 45 days prior to replacement about the potential for increased Pb levels;
  - Collect sample within 72 hours of replacement and mail/post results within 3 days of receipt of results.
- Systems can discontinue LSLR whenever ≤ Pb AL in tap water for 2 consecutive monitoring periods.

For additional information on the LCR, call the Safe Drinking Water Hotline at 1-800-426-4791; visit the EPA web site at www.epa.gov/safewater/lcrmr/implement.html; or contact your State drinking water representative.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

NOV 23 2004

OFFICE OF
WATER

MEMORANDUM

SUBJECT: Lead and Copper Rule - Clarification of Requirements for Collecting Samples and Calculating Compliance

FROM: Benjamin H. Grumbles Ben H Grumbles
Acting Assistant Administrator

TO: Regional Administrators
Water Division Directors
Regions I-X

This memo reiterates and clarifies elements of the Lead and Copper Rule (LCR) associated with the collection and management of lead and copper samples and the calculation of the lead 90th percentile for compliance. Over the past several months, Headquarters has been conducting a national review of implementation of the LCR. This review consists of both data analysis and feedback from expert panels on aspects of the rule. Headquarters is continuing its review, and will be making a determination in early 2005 on specific areas of the rule that may require changes in regulation or need clarification through guidance or training.

One area identified for additional guidance is the management of lead and copper samples and the calculation of the lead 90th percentile. Because the need for additional guidance was identified in both Headquarters' data review and the expert panels, Headquarters is addressing this area prior to the final determination on rule and guidance changes. This guidance reflects the requirements of the LCR as it is currently written. These issues may be revisited if EPA makes a determination that changes should be made to the LCR.

1) What samples are used to calculate the 90th percentile?

We have received several questions regarding what tap samples should be used to calculate the 90th percentile for lead, specifically, where utilities collect samples beyond the minimum number required by the regulations. EPA regulations require water systems to develop a targeted sampling pool, focused on those sites with the greatest risk of lead leaching. All compliance samples used to determine the 90th percentile must come from that sampling pool. All sample results from a system's sampling pool during the monitoring period must be included in the 90th percentile calculation, even if this includes more samples than the required minimum number needed for compliance. [40 CFR 141.86(e)] For example, consider a situation where a system sends out sample kits to 150 households to ensure that it will have a sufficient number of samples to meet its required 100 samples for compliance. If the system receives sample results from 140 households, it would use the results of the 140 samples in calculating the 90th percentile.

In some cases, a utility may choose to take a confirmation sample to verify a high or low concentration. It is entirely possible for the concentration of a confirmation sample to be significantly higher or lower than the concentration of the original sample. However, where confirmation samples are taken, the results of the original and confirmation sample must be used in calculating the 90th percentile. The LCR does not allow substitution of results with "confirmation" samples, nor does it allow the averaging of initial and confirmation samples as a single sampling result. While we support re-sampling at a home with high lead levels, all sample results from the sampling pool collected within the monitoring period must be included in the calculation.

Inclusion of samples in
90th Percentile Calculations

40 CFR 141.86(e) "The results of any additional monitoring conducted in addition to the minimum requirements of this section shall be considered by the system and the state in making any determinations (i.e.; calculating the 90th percentile lead or copper level) under this subpart."

40 CFR 141.80(c)(3)(i) "The results of <u>all lead and copper samples taken during a monitoring period</u> shall be placed in ascending order from the sample with the lowest concentration to the sample with the highest concentration. ..." [emphasis added]

2) What should utilities do with sample results from customer-requested sampling programs?

EPA regulations require water systems to develop a targeted sampling pool, focused on those sites with the greatest risk of lead leaching. All compliance samples used to determine the 90th percentile must come from that sampling pool. [40 CFR 141.80(c)(1)] ("Samples collected at sites not meeting the targeting criteria may not be used in calculating the 90th percentile lead and copper levels." 56 Fed Reg. 26518 (June 7, 1991)). Maintaining a consistent set of compliance sample sites provides the system with a baseline against which to measure the 90th percentile over time. If a system designates sites which were not sampled during previous monitoring periods, it must notify the state and include an explanation of why the sampling sites have changed. [40 CFR 141.90(a)(1)(v) and 141.90(h)(2)]

In addition to compliance sampling, many water systems have additional programs to test for lead in drinking water at the request of homeowners. Customer-requested samples that are not collected as part of the system's regular compliance sampling pool may or may not meet the sample site selection criteria, and the system may not have sufficient information to determine whether they do or not. Including results from samples that do not meet the criteria could inappropriately reduce the 90th percentile value. Therefore, samples collected under these programs should not be used to calculate the 90th percentile, except in cases where the system is reasonably able to determine that the site selection criteria for compliance sampling are satisfied.

However, even though these customer-requested samples are not used for the 90th percentile calculation, the sample results must still be provided to the state. [40 CFR 141.90(g)] If a significant number of customer-requested samples are above the lead action level, the state should re-evaluate the corrosion control used by the system and the composition of the compliance sampling pool. Further, where any results are above the action level, we strongly urge systems to follow up with the affected customers to provide them with information on ways to reduce their risk of exposure to elevated lead levels in drinking water.

3) What should states do with samples taken outside of the sampling compliance period?

The regulations require that systems on reduced monitoring collect samples during the period between June and September, unless the state has approved an alternate period. [40 CFR 141.86(d)(4)(iv)] Only those samples collected during the compliance monitoring period may be included in the 90th percentile calculation. [40 CFR 141.80(c)(3)]

An exception to this is where a state invalidates a sample and the system must collect a replacement sample in order to have a sufficient number with which to calculate compliance. The system must collect its replacement sample within 20 days of the invalidation. Even if the date of collection occurs after the closure of the monitoring period (but within 20 days of the invalidation), the results must be included in the 90th percentile calculation. [40 CFR 141.86(f)(4)]

Although samples collected outside the sampling compliance period should not be used in the compliance calculation, they must still be provided to the state [40 CFR 141.90(g)], as is the case with customer-requested samples.

4) What should states do to calculate compliance if the minimum number of samples are not collected?

As noted in guidance released earlier this year[1], states must calculate the 90th percentile even if the minimum number of samples are not collected. The LCR states that the 90th percentile level is calculated based on "all samples taken during a monitoring period" and does not require that the minimum required number of samples must be collected in order to calculate the 90th percentile level. [40 CFR 141.80(c)]

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[1] See March 9, 2004 memorandum from Cynthia Dougherty to Jane Downing at http://www.epa.gov/safewater/lcrmr/pdfs/memo_lcmr_lead_compliance_calculation.pdf

A system which fails to collect the minimum required number of samples incurs a monitoring and reporting violation and is thus required to conduct Tier 3 Public Notification (PN) [40 CFR 141.204(a)] and report the violation in its Consumer Confidence Report (CCR) [40 CFR 141.153(f)(1)]. The system will return to compliance for the monitoring and reporting violation when it completes these tasks and has completed appropriate monitoring and reporting for two consecutive 6-month monitoring periods (or one round of monitoring for a system on reduced monitoring). [*State Implementation Guidance for the LCRMR*, EPA-816-R-01-021]

Calculating the 90th Percentile

40 CFR §141.80(c)(3) – "The 90th percentile lead and copper levels shall be computed as follows:
(i) The results of all lead and copper samples taken during a monitoring period shall be placed in ascending order from the sample with the lowest concentration to the sample with the highest concentration. Each sampling result shall be assigned a number, ascending by single integers beginning with the number 1 for the sample with the lowest contaminant level. The number assigned to the sample with the highest contaminant level shall be equal to the total number of samples taken.
(ii) The number of samples taken during the monitoring period shall be multiplied by 0.9.
(iii) The contaminant concentration in the numbered sample yielded by the calculation in paragraph (c)(3)(ii) is the 90th percentile contaminant level.
(iv) For water systems serving less than 100 people that collect 5 samples per monitoring period, the 90th percentile is computed by taking the average of the highest and second highest concentrations.

5) What is a proper sample?

We have received numerous requests to clarify the LCR with respect to proper samples and grounds for invalidation.

The LCR was designed to ensure that samples are collected from locations which have the highest risk of elevated lead concentrations. The rule established a tiering system (Attachment A) that would guide utilities in selecting locations for tap sampling that are considered high risk and requires that the sampling pool be comprised of Tier 1 sites, if they are available. [40 CFR 141.86(a)]

The LCR also defines a proper sample as a first draw sample, 1 liter in volume, that is taken after water has been standing in plumbing for at least six hours, and from an interior tap typically used for consumption – cold water kitchen or bathroom sink tap in residences. [40 CFR 141.86(b)(2)] There is no outer limit on standing time.

To ensure that sampling is conducted properly, the LCR requires that samples be collected by the system or by residents if they have been properly instructed by the water system. As added insurance that the system gives proper instructions, the rule does not allow water systems to challenge sample results based on alleged homeowner errors in sample collection. [40 CFR 141.86(b)(2)]

6) How can utilities avoid problems with sample collection?

In order to avoid any problems with sample collection, the utility may wish to do the sampling itself or review the sample collection information before sending it to the lab. If the utility chooses to use residents to perform the sampling, it should provide clear instructions and a thorough chain-of-custody form for residents to fill out when the sample is taken. This will allow the laboratory or utility to eliminate improperly collected samples prior to the actual analysis. For example, if a sample bottle is only half full, then it should not be analyzed by the laboratory. Likewise, if the documentation accompanying the sample indicates that it was taken from an outside tap, the sample should not be analyzed. Systems may need to make arrangements to collect replacement samples for samples that are not analyzed by the laboratory.

Once a sample is analyzed, the results may not be challenged by the water system. As explained by Question #1 of this memorandum, the results for all samples from the compliance sampling pool must be included in the 90th percentile calculation unless there are grounds for invalidation. Improper sampling by residents is not a grounds for invalidation under 40 CFR 141.86(f).

7) On what grounds may a sample be invalidated?

The regulations allow the state to invalidate a lead or copper tap sample only if it can document that at least one of the following conditions has occurred:

1. The laboratory establishes that improper sample analysis caused erroneous results;
2. The state determines that the sample was taken from a site that did not meet the site selection criteria of this section;
3. The sample container was damaged in transit; or
4. There is substantial reason to believe that the sample was subject to tampering. [40 CFR 141.86(f)(1)]

We interpret the second condition to mean a site that is not part of the compliance sampling pool, that has not been identified as a Tier 1 or other high risk site, or that has been altered in such a way that it no longer meets the criteria of a high-risk site (e.g., new plumbing or the addition of a water softener).

It is important to note that states may not invalidate a sample solely on the grounds that a follow-up sample result is higher or lower than that of the original sample. [40 CFR 141.86(f)(3)] The system must report the results of all the samples to the state, and provide supporting documentation for all samples it believes should be invalidated. [40 CFR 141.86(f)(2)] The state must provide its formal decision on whether or not to invalidate the sample(s) in writing. If a state makes a determination to invalidate the sample, the decision and the rationale for the decision must be provided in writing. [40 CFR 141.86(f)(3)]

In conducting the national implementation review, we have noticed that some utilities may have requested invalidation of samples because they believe that there was improper sampling on the part of the homeowner (e.g., drawing water from the incorrect tap). This is a concern because there may be a tendency to only consider sampling errors when there are high results, even though there could be sampling errors that would lead to artificially low results (e.g., collecting a sample after the line was flushed). In any event, EPA takes a strict interpretation of the invalidation requirements in the LCR. If a system allows residents to perform sampling as part of the targeted sampling pool, the system may not challenge the accuracy of sampling results because it believes there were errors in sample collection. [40 CFR 141.86(b)(2)] The state may only invalidate samples based on the criteria described above.

In sum, if a water system (1) sends a sample bottle to a home within its compliance sampling pool, (2) receives the sample back from the homeowner, (3) sends the sample to the laboratory for analysis, and (4) receives results from the analysis back from the lab; that result must be used in calculating the 90th percentile. The only exception to this is if the state invalidates the result in accordance with the regulation.

Conclusion

The Agency is continuing its wide-ranging review of implementation of the LCR and will use the information to determine what changes should be made to existing guidance, training and/or the regulatory requirements. This memo should help to provide clarification on issues related to calculating the 90th percentile and proper management of tap samples as required under the LCR. Please work with your states to ensure that they understand the requirements so that they may work with the public water systems under their jurisdiction to address any misinterpretations of the regulations. If you have additional questions or concerns, please contact me or have your staff contact Cynthia Dougherty, Director of the Office of Ground Water and Drinking Water at (202) 564-3750, or Ronald Bergman, Associate Chief of the Protection Branch in the Office of Ground Water and Drinking Water, at (202) 564-3823.

Attachment

cc: Regional Drinking Water Branch Chiefs
James Taft, Association of State Drinking Water Administrators

Attachment A

Tiering Classification System for Selection of Monitoring Sites

Tiering Classification

If you are a Community Water System	***If you are an Non-transient Noncommunity Water System***
Tier l sampling sites are single family structures: with copper pipes with lead solder installed after 1982 *(but before the effective date of your State's lead ban)* or contain lead pipes; and/or that are served by a lead service line. ***Note :*** When multiple-family residences (MFRs) comprise at least 20% of the structures served by a water system, the system may count them as Tier 1 sites. **Tier 2** sampling sites consist of buildings, including MFRs: with copper pipes with lead solder installed after 1982 *(but before effective date of your State's lead ban)* or contain lead pipes; and/or that are served by a lead service line. **Tier 3** sampling sites are single family structures w/ copper pipes having lead solder installed before 1983.	**Tier l** sampling sites consist of buildings: with copper pipes with lead solder installed after 1982 *(but before the effective date of your State's lead ban)*or contain lead pipes; and/or that are served by a lead service line. **Tier 2** sampling sites consist of buildings with copper pipes with lead solder installed before 1983. **Tier 3**: Not applicable.

Note:

- All States were required to ban the use of lead solder in all public water systems, and all homes and buildings connected to such systems by June 1988 (most States adopted the ban in 1987 or 1988). Contact the Drinking Water Program in your State to find out the effective date.
- A community water system with insufficient tier 1, tier 2 and tier 3 sampling sites, or an non-transient noncommunity water system with insufficient tier 1 and tier 2 sites, shall complete its sampling pool with representative sites throughout the distribution system. For the purposes of this paragraph, a representative site is a site in which the plumbing materials used at that site would be commonly found at other sites served by the water system. [40 CFR 141.86(a)(5) and (7)]

Source: *Lead and Copper Monitoring and Reporting Guidance for Public Water Systems*, EPA-816-R-02-009

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United States
Environmental Protection
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Office of Water
(4606)

EPA 816-F-01-035
November 2001
www.epa.gov/safewater

Total Coliform Rule:
A Quick Reference Guide

Overview of the Rule

Title	**Total Coliform Rule (TCR)** **54 FR 27544-27568, June 29, 1989, Vol. 54, No. 124**[1]
Purpose	**Improve public health protection by reducing fecal pathogens to minimal levels through control of total coliform bacteria, including fecal coliforms and *Escherichia coli (E. coli)*.**
General Description	**Establishes a maximum contaminant level (MCL) based on the presence or absence of total coliforms, modifies monitoring requirements including testing for fecal coliforms or *E. coli,* requires use of a sample siting plan, and also requires sanitary surveys for systems collecting fewer than five samples per month.**
Utilities Covered	**The TCR applies to all public water systems.**

Public Health Benefits

Implementation of the TCR has resulted in . . .	▸ **Reduction in risk of illness from disease causing organisms associated with sewage or animal wastes. Disease symptoms may include diarrhea, cramps, nausea, and possibly jaundice, and associated headaches and fatigue.**

What are the Major Provisions?

ROUTINE Sampling Requirements

- **Total coliform samples must be collected at sites which are representative of water quality throughout the distribution system according to a written sample siting plan subject to state review and revision.**
- **Samples must be collected at regular time intervals throughout the month except groundwater systems serving 4,900 persons or fewer may collect them on the same day.**
- **Monthly sampling requirements are based on population served (see table on next page for the minimum sampling frequency).**
- **A reduced monitoring frequency may be available for systems serving 1,000 persons or fewer and using only ground water if a sanitary survey within the past 5 years shows the system is free of sanitary defects (the frequency may be no less than 1 sample/quarter for community and 1 sample/year for non-community systems).**
- **Each total coliform-positive routine sample must be tested for the presence of fecal coliforms or *E. coli*.**
- **If any routine sample is total coliform-positive, repeat samples are required.**

REPEAT Sampling Requirements

- **Within 24 hours of learning of a total coliform-positive ROUTINE sample result, at least 3 REPEAT samples must be collected and analyzed for total coliforms:**
  - **One REPEAT sample must be collected from the same tap as the original sample.**
  - **One REPEAT sample must be collected within five service connections upstream.**
  - **One REPEAT sample must be collected within five service connections downstream.**
  - **Systems that collect 1 ROUTINE sample per month or fewer must collect a 4th REPEAT sample.**
- **If any REPEAT sample is total coliform-positive:**
  - **The system must analyze that total coliform-positive culture for fecal coliforms or *E.coli*.**
  - **The system must collect another set of REPEAT samples, as before, unless the MCL has been violated and the system has notified the state.**

Additional ROUTINE Sample Requirements

- **A positive ROUTINE or REPEAT total coliform result requires a minimum of five ROUTINE samples be collected the following month the system provides water to the public unless waived by the state.**

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[1] The June 1989 Rule was revised as follows: Corrections and Technical Amendments, 6/19/90 and Partial Stay of Certain Provisions (Variance Criteria) 56 FR 1556-1557, Vol 56, No 10.

Note: The TCR is currently undergoing the 6 year review process and may be subject to change.

Public Water System ROUTINE Monitoring Frequencies

Population	Minimum Samples/ Month	Population	Minimum Samples/ Month	Population	Minimum Samples/ Month
25-1,000*	1	21,501-25,000	25	450,001-600,000	210
1,001-2,500	2	25,001-33,000	30	600,001-780,000	240
2,501-3,300	3	33,001-41,000	40	780,001-970,000	270
3,301-4,100	4	41,001-50,000	50	970,001-1,230,000	300
4,101-4,900	5	50,001-59,000	60	1,230,001-1,520,000	330
4,901-5,800	6	59,001-70,000	70	1,520,001-1,850,000	360
5,801-6,700	7	70,001-83,000	80	1,850,001-2,270,000	390
6,701-7,600	8	83,001-96,000	90	2,270,001-3,020,000	420
7,601-8,500	9	96,001-130,000	100	3,020,001-3,960,000	450
8,501-12,900	10	130,001-220,000	120	≥ 3,960,001	480
12,901-17,200	15	220,001-320,000	150		
17,201-21,500	20	320,001-450,000	180		

*Includes PWSs which have at least 15 service connections, but serve <25 people.

What are the Other Provisions?

Systems collecting fewer than 5 ROUTINE samples per month . . .	Must have a sanitary survey every 5 years (or every 10 years if it is a non-community water system using protected and disinfected ground water).**
Systems using surface water or ground water under the direct influence of surface water (GWUDI) and meeting filtration avoidance criteria . . .	Must collect and have analyzed one coliform sample each day the turbidity of the source water exceeds 1 NTU. This sample must be collected from a tap near the first service connection.

** As per the IESWTR, states must conduct sanitary surveys for community surface water and GWUDI systems in this category every 3 years (unless reduced by the state based on outstanding performance).

How is Compliance Determined?

- Compliance is based on the presence or absence of total coliforms.
- Compliance is determined each calendar month the system serves water to the public (or each calendar month that sampling occurs for systems on reduced monitoring).
- The results of ROUTINE and REPEAT samples are used to calculate compliance.

A Monthly MCL Violation is Triggered if:

A system collecting fewer than 40 samples per month . . .	Has greater than 1 ROUTINE/REPEAT sample per month which is total coliform-positive.
A system collecting at least 40 samples per month . . .	Has greater than 5.0 percent of the ROUTINE/REPEAT samples in a month total coliform-positive.

An Acute MCL Violation is Triggered if:

Any public water system . . .	Has any fecal coliform- or *E. coli*-positive REPEAT sample ***or*** has a fecal coliform- or *E. coli*-positive ROUTINE sample followed by a total coliform-positive REPEAT sample.

What are the Public Notification and Reporting Requirements?

For a Monthly MCL Violation	- The violation must be reported to the state no later than the end of the next business day after the system learns of the violation. - The public must be notified within 14 days.[2]
For an Acute MCL Violation	- The violation must be reported to the state no later than the end of the next business day after the system learns of the violation. - The public must be notified within 72 hours.[2]
Systems with ROUTINE or REPEAT samples that are fecal coliform- or *E. coli*-positive . . .	Must notify the state by the end of the day they are notified of the result or by the end of the next business day if the state office is already closed.

For additional information on the TCR

Call the Safe Drinking Water Hotline at 1-800-426-4791; visit the EPA web site at www.epa.gov/safewater/mdbp/mdbp.html; or contact your state drinking water representative.

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[2] The revised Public Notification Rule will extend the period allowed for public notice of monthly violations to 30 days and shorten the period for acute violations to 24 hours. These revisions are effective for all systems by May 6, 2002 and are detailed in 40 CFR Subpart Q.

United States
Environmental Protection
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Office of Water
(4606)

EPA 816-F-01-010
May 2001
www.epa.gov/safewater

Stage 1 Disinfectants and Disinfection Byproducts Rule: A Quick Reference Guide

Overview of the Rule

Title	**Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 DBPR) 63 FR 69390 - 69476, December 16, 1998, Vol. 63, No. 241 Revisions to the Interim Enhanced Surface Water Treatment Rule (IESWTR), the Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 DBPR), and Revisions to State Primacy Requirements to Implement the Safe Drinking Water Act (SDWA) Amendments 66 FR 3770, January 16, 2001, Vol 66, No. 29**
Purpose	**Improve public health protection by reducing exposure to disinfection byproducts. Some disinfectants and disinfection byproducts (DBPs) have been shown to cause cancer and reproductive effects in lab animals and suggested bladder cancer and reproductive effects in humans.**
General Description	**The Stage 1 DBPR is the first of a staged set of rules that will reduce the allowable levels of DBPs in drinking water. The new rule establishes seven new standards and a treatment technique of enhanced coagulation or enhanced softening to further reduce DBP exposure. The rule is designed to limit capital investments and avoid major shifts in disinfection technologies until additional information is available on the occurrence and health effects of DBPs.**
Utilities Covered	**The Stage 1 DBPR applies to all sizes of community water systems and nontransient noncommunity water systems that add a disinfectant to the drinking water during any part of the treatment process and transient noncommunity water systems that use chlorine dioxide.**

Public Health Benefits

Implementation of the Stage 1 DBPR will result in . . .	▸ **As many as 140 million people receiving increased protection from DBPs.** ▸ **24 percent average reduction nationally in trihalomethane levels.** ▸ **Reduction in exposure to the major DBPs from use of ozone (DBP = bromate) and chlorine dioxide (DBP = chlorite).**
Estimated impacts of the Stage 1 DBPR include . . .	▸ **National capital costs: $2.3 billion** ▸ **National total annualized costs to utilities: $684 million** ▸ **95 percent of households will incur an increase of less than $1 per month.** ▸ **4 percent of households will incur an increase of $1-10 per month.** ▸ **<1 percent of households will incur an increase of $10-33 per month.**

Critical Deadlines and Requirements

For Drinking Water Systems

January 1, 2002	**Surface water systems and ground water systems under the direct influence of surface water serving ≥ 10,000 people must comply with the Stage 1 DBPR requirements.**
January 1, 2004	**Surface water systems and ground water systems under the direct influence of surface water serving < 10,000, and all ground water systems must comply with the Stage 1 DBPR requirements.**

For States

December 16, 2000	**States submit Stage 1 DBPR primacy revision applications to EPA (triggers interim primacy).**
December 16, 2002	**Primacy extension deadline - all states with an extension must submit primacy revision applications to EPA.**

Regulated Contaminants/Disinfectants

Regulated Contaminants	MCL (mg/L)	MCLG (mg/L)	Regulated Disinfectants	MRDL* (mg/L)	MRDLG* (mg/L)
Total Trihalomethanes (TTHM)	**0.080**		**Chlorine**	**4.0 as Cl_2**	**4**
Chloroform Bromodichloromethane Dibromochloromethane Bromoform		- zero 0.06 zero			
Five Haloacetic Acids (HAA5)	**0.060**		**Chloramines**	**4.0 as Cl_2**	**4**
Monochloroacetic acid Dichloroacetic acid Trichloroacetic acid Bromoacetic acid Dibromoacetic acid		- zero 0.3 - -	**Chlorine dioxide**	**0.8**	**0.8**
Bromate (plants that use ozone)	**0.010**	**zero**	***Stage 1 DBPR includes maximum residual disinfectant levels (MRDLs) and maximum residual disinfectant level goals (MRDLGs) which are similar to MCLs and MCLGs, but for disinfectants.**		
Chlorite (plants that use chlorine dioxide)	**1.0**	**0.8**			

Treatment Technique

Enhanced coagulation/enhanced softening to improve removal of DBP precursors (See Step 1 TOC Table) for systems using conventional filtration treatment.

Step 1 TOC Table - Required % Removal of TOC

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

[1] **Systems meeting at least one of the alternative compliance criteria in the rule are not required to meet the removals in this table.**

[2] **Systems practicing softening must meet the TOC removal requirements in the last column to the right**

Routine Monitoring Requirements

	Coverage	Monitoring Frequency	Compliance
TTHM/HAA5	**Surface and ground water under the direct influence of surface water serving ≥ 10,000**	**4/plant/quarter**	**Running annual average**
	Surface and ground water under the direct influence of surface water serving 500 - 9,999	**1/plant/quarter**	**Running annual average**
	Surface and ground water under the direct influence of surface water serving < 500	**1/plant/year in month of warmest water temperature****	**Running annual average of increased monitoring**
	Ground water serving ≥ 10,000	**1/plant/quarter**	**Running annual average**
	Ground water serving < 10,000	**1/plant/year in month of warmest water temperature****	**Running annual average of increased monitoring**
Bromate	**Ozone plants**	**Monthly**	**Running annual average**
Chlorite	**Chlorine dioxide plants**	**Daily at entrance to distribution system; monthly in distribution system**	**Daily/follow-up monitoring**
Chlorine dioxide	**Chlorine dioxide plants**	**Daily at entrance to distribution system**	**Daily/follow-up monitoring**
Chlorine/Chloramines	**All systems**	**Same location and frequency as TCR sampling**	**Running annual average**
DBP precursors	**Conventional filtration**	**Monthly for total organic carbon and alkalinity**	**Running annual average**

** System must increase monitoring to 1 sample per plant per quarter if an MCL is exceeded.

For additional information on the Stage 1 DBPR

Call the Safe Drinking Water Hotline at 1-800-426-4791; visit the EPA web site at www.epa.gov/safewater; or contact your State drinking water representative.

Additional material is available at www.epa.gov/safewater/mdbp/implement.html.

United States
Environmental Protection
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Office of Water
(4606)

EPA 816-F-01-011
May 2001
www.epa.gov/safewater

Interim Enhanced Surface Water Treatment Rule: A Quick Reference Guide

Overview of the Rule

Title	Interim Enhanced Surface Water Treatment Rule (IESWTR) 63 FR 69478 - 69521, December 16, 1998, Vol. 63, No. 241 Revisions to the Interim Enhanced Surface Water Treatment Rule (IESWTR), the Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 DBPR), and Revisions to State Primacy Requirements to Implement the Safe Drinking Water Act (SDWA) Amendments 66 FR 3770, January 16, 2001, Vol 66, No. 29
Purpose	Improve public health control of microbial contaminants, particularly *Cryptosporidium*. Prevent significant increases in microbial risk that might otherwise occur when systems implement the Stage 1 Disinfectants and Disinfection Byproducts Rule.
General Description	Builds upon treatment technique approach and requirements of the 1989 Surface Water Treatment Rule. Relies on existing technologies currently in use at water treatment plants.
Utilities Covered	Sanitary survey requirements apply to all public water systems using surface water or ground water under the direct influence of surface water, regardless of size. All remaining requirements apply to public water systems that use surface water or ground water under the direct influence of surface water and serve 10,000 or more people.

Major Provisions

Regulated Contaminants

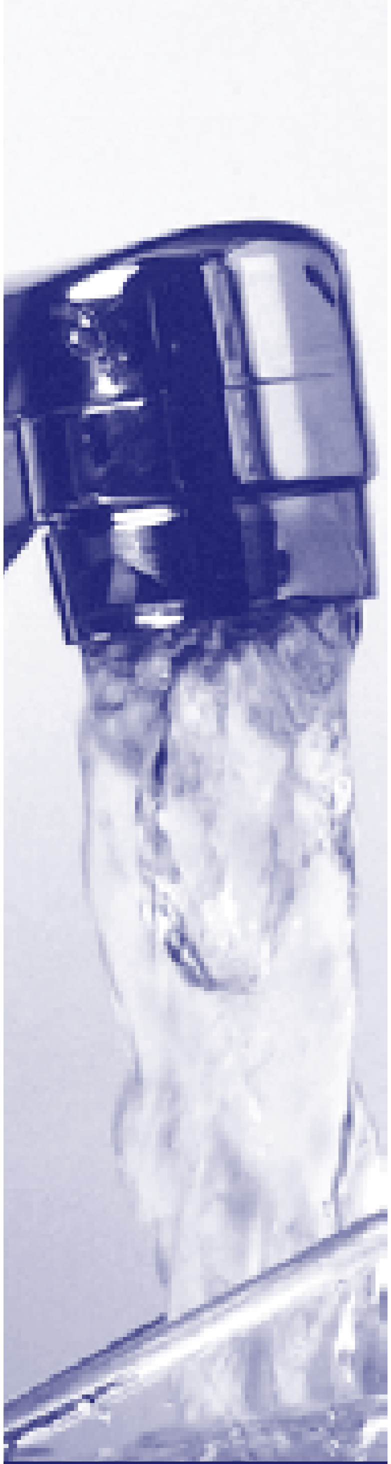
Cryptosporidium	▸ Maximum contaminant level goal (MCLG) of zero. ▸ 99 percent (2-log) physical removal for systems that filter. ▸ Include in watershed control program for unfiltered systems.
Turbidity Performance Standards	Conventional and direct filtration combined filter effluent: ▸ ≤ 0.3 nephelometric turbidity units (NTU) in at least 95 percent of measurements taken each month. ▸ Maximum level of 1 NTU.

Turbidity Monitoring Requirements
(Conventional and Direct Filtration)

Combined Filter Effluent	▸ Performed every 4 hours to ensure compliance with turbidity performance standards.
Individual Filter Effluent	▸ Performed continuously (every 15 minutes) to assist treatment plant operators in understanding and assessing filter performance.

Additional Requirements

- Disinfection profiling and benchmarking.
- Construction of new uncovered finished water storage facilities prohibited.
- Sanitary surveys, conducted by the state, for all surface water and ground water under the direct influence of surface water systems regardless of size (every 3 years for community water systems and every 5 years for noncommunity water systems).



Profiling and Benchmarking

Public water systems must evaluate impacts on microbial risk before changing disinfection practices to ensure adequate protection is maintained. The three major steps are:

- **Determine if a public water system needs to profile based on TTHM and HAA5 levels (applicability monitoring)**
- **Develop a disinfection profile that reflects daily *Giardia lamblia* inactivation for at least a year (systems using ozone or chloramines must also calculate inactivation of viruses)**
- **Calculate a disinfection benchmark (lowest monthly inactivation) based on the profile and consult with the state prior to making a significant change to disinfection practices**

Critical Deadlines and Requirements

For Drinking Water Systems

February 16, 1999	**Construction of uncovered finished water reservoirs is prohibited.**
March 1999	**Public water systems lacking ICR or other occurrence data begin 4 quarters of applicability monitoring for TTHM and HAA5 to determine if disinfection profiling is necessary.**
April 16, 1999	**Systems that have 4 consecutive quarters of HAA5 occurrence data that meet the TTHM monitoring requirements must submit data to the state to determine if disinfection profiling is necessary.**
December 31, 1999	**Public water systems with ICR data must submit it to states to determine if disinfection profiling is necessary.**
April 1, 2000	**Public water systems must begin developing a disinfection profile if their annual average (based on 4 quarters of data) for TTHM is greater than or equal to 0.064 mg/L or HAA5 is greater than or equal to 0.048 mg/L.**
March 31, 2001	**Disinfection profile must be complete.**
January 1, 2002	**Surface water systems or ground water under the direct influence of surface water systems serving 10,000 or more people must comply with all IESWTR provisions (e.g., turbidity standards, individual filter monitoring).**

For States

December 16, 2000	**States submit IESWTR primacy revision applications to EPA (triggers interim primacy).**
January 2002	**States begin first round of sanitary surveys.**
December 16, 2002	**Primacy extension deadline - all states with an extension must submit primacy revision applications to EPA.**
December 2004	**States must complete first round of sanitary surveys for community water systems.**
December 2006	**States must complete first round of sanitary surveys for noncommunity water systems.**

Public Health Benefits

Implementation of the IESWTR will result in . . .	▸ **Increased protection against gastrointestinal illnesses from *Cryptosporidium* and other pathogens through improvements in filtration.** ▸ **Reduced likelihood of endemic illness from *Cryptosporidium* by 110,000 to 463,000 cases annually.** ▸ **Reduced likelihood of outbreaks of cryptosporidiosis.**
Estimated impacts of the IESWTR include . . .	▸ **National total annualized cost: $307 million** ▸ **92 percent of households will incur an increase of less than $1 per month.** ▸ **Less than 1 percent of households will incur an increase of more than $5 per month (about $8 per month).**

For additional information on the IESWTR

Call the Safe Drinking Water Hotline at 1-800-426-4791; visit the EPA web site at www.epa.gov/safewater; or contact your State drinking water representative.

Additional material is available at www.epa.gov/safewater/mdbp/implement.html.

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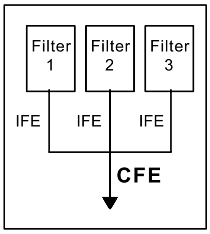
Long Term 1 Enhanced Surface Water Treatment Rule: A Quick Reference Guide

Overview of the Rule

Title	Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR) 67 FR 1812, January 14, 2002, Vol. 67, No. 9
Purpose	Improve public health protection through the control of microbial contaminants, particularly *Cryptosporidium*. Prevent significant increases in microbial risk that might otherwise occur when systems implement the Stage 1 Disinfectants and Disinfection Byproducts Rule.
General Description	Builds upon the requirements of the 1989 Surface Water Treatment Rule (SWTR). Smaller system counterpart of the Interim Enhanced Surface Water Treatment Rule (IESWTR).
Utilities Covered	Public water systems that use surface water or ground water under the direct influence of surface water (GWUDI) and serve fewer than 10,000 people.

Major Provisions

Control of *Cryptosporidium*	▸ The maximum contaminant level goal (MCLG) is set at zero. ▸ Filtered systems must physically remove 99% (2-log) of *Cryptosporidium*. ▸ Unfiltered systems must update their watershed control programs to minimize the potential for contamination by *Cryptosporidium* oocysts. ▸ *Cryptosporidium* is included as an indicator of GWUDI.
Combined Filter Effluent (CFE) Turbidity Performance Standards 	***Specific CFE turbidity requirements depend on the type of filtration used by the system.*** Conventional and direct filtration: ▸ ≤ 0.3 nephelometric turbidity units (NTU) in at least 95% of measurements taken each month. ▸ Maximum level of turbidity: 1 NTU. Slow sand and diatomaceous earth (DE) filtration: ▸ Continue to meet CFE turbidity limits specified in the SWTR: • 1 NTU in at least 95% of measurements taken each month. • Maximum level of turbidity: 5 NTU. Alternative technologies (other than conventional, direct, slow sand, or DE): ▸ Turbidity levels are established by the State based on filter demonstration data submitted by the system. • State-set limits must not exceed 1 NTU (in at least 95% of measurements) or 5 NTU (maximum).

Turbidity Monitoring Requirements

Combined Filter Effluent	▸ Performed at least every 4 hours to ensure compliance with CFE turbidity performance standards.[1]
Individual Filter Effluent (IFE) (for systems using conventional and direct filtration only)	***Since the CFE may meet regulatory requirements even though one filter is producing high turbidity water, the IFE is measured to assist conventional and direct filtration treatment plant operators in understanding and assessing individual filter performance.*** ▸ Performed continuously (recorded at least every 15 minutes). ▸ Systems with two or fewer filters may conduct continuous monitoring of CFE turbidity in place of individual filter effluent turbidity monitoring. ▸ Certain follow-up actions are required if the IFE turbidity (or CFE for systems with two filters) exceeds 1.0 NTU in 2 consecutive readings or more (i.e., additional reporting, filter self-assessments, and/or comprehensive performance evaluations (CPEs)).

For additional information on the LT1ESWTR

Call the Safe Drinking Water Hotline at 1-800-426-4791; visit the EPA web site at www.epa.gov/safewater/mdbp/lt1eswtr.html; or contact your State drinking water representative.

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[1] This frequency may be reduced by the State to once per day for systems using slow sand/alternative filtration or for systems serving 500 persons or fewer regardless of the type of filtration used.

Disinfection Profiling and Benchmarking Requirements

Community and non-transient non-community public water systems must evaluate impacts on microbial risk before changing disinfection practices to ensure adequate microbial protection is maintained. This is accomplished through a process called disinfection profiling and benchmarking.

What are the disinfection profiling and benchmarking requirements?

- **Systems must develop a disinfection profile, which is a graphical compilation of weekly inactivation of *Giardia lamblia*, taken on the same calendar day each week over 12 consecutive months. (Systems using chloramines, ozone, or chlorine dioxide for primary disinfection must also calculate inactivation of viruses). Results must be available for review by the State during sanitary surveys.**
- **A State may deem a profile unnecessary if the system has sample data collected after January 1, 1998–during the month of warmest water temperature and at maximum residence time in the distribution system–indicating TTHM levels are below 0.064 mg/L and HAA5 levels are below 0.048 mg/L.**
- **Prior to making a significant change to disinfection practices, systems required to develop a profile must calculate a disinfection benchmark and consult with the State. The benchmark is the calculation of the lowest monthly average of inactivation based on the disinfection profile.**

Additional Requirements

- **Construction of new uncovered finished water reservoirs is prohibited.**

Critical Deadlines and Requirements

For Drinking Water Systems

March 15, 2002	Construction of uncovered finished reservoirs is prohibited.
July 1, 2003	No later than this date, systems serving between 500-9,999 persons must report to the State: ▸ Results of optional monitoring which show levels of TTHM < 0.064 mg/L and HAA5 < 0.048 mg/L, OR ▸ System has started profiling.
January 1, 2004	No later than this date, systems serving fewer than 500 persons must report to the State: ▸ Results of optional monitoring which show levels of TTHM < 0.064 mg/L and HAA5 < 0.048 mg/L, OR ▸ System has started profiling.
June 30, 2004	Systems serving between 500 and 9,999 persons must complete their disinfection profile unless the State has determined it is unnecessary.
December 31, 2004	Systems serving fewer than 500 persons must complete their disinfection profile unless the State has determined it is unnecessary.
January 14, 2005	Surface water systems or GWUDI systems serving fewer than 10,000 people must comply with the applicable LT1ESWTR provisions (e.g., turbidity standards, individual filter monitoring, *Cryptosporidium* removal requirements, updated watershed control requirements for unfiltered systems).

For States

January 2002	As per the IESWTR, States begin first round of sanitary surveys (at least every 3 years for community water systems and every 5 years for non-community water systems).
October 14, 2003	States are encouraged to submit final primacy applications to EPA.
January 14, 2004	Final primacy applications must be submitted to EPA unless granted an extension.
December 2004	States must complete first round of sanitary surveys for community water systems (as per the IESWTR).
January 14, 2006	Final primacy revision applications from States with approved 2-year extension agreements must be submitted to EPA.
December 2006	States must complete first round of sanitary surveys for non-community water systems (as per the IESWTR).

Public Health Benefits

Implementation of the LT1ESWTR will result in . . .	▸ Increased protection against gastrointestinal illnesses from *Cryptosporidium* and other pathogens through improvements in filtration. ▸ Reduced likelihood of endemic illness from *Cryptosporidium* by an estimated 12,000 to 41,000 cases annually. ▸ Reduced likelihood of outbreaks of cryptosporidiosis.
Estimated impacts of the LT1ESWTR include . . .	▸ National total annualized cost: $39.5 million. ▸ 90% of affected households will incur an increase of less than $1.25 per month. ▸ One percent of affected households are likely to incur an increase of more than $10 per month.

United States
Environmental Protection
Agency

Office of Water
(4606)

EPA 816-F-01-019
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www.epa.gov/safewater

Filter Backwash Recycling Rule: A Quick Reference Guide

Overview of the Rule

Title	**Filter Backwash Recycling Rule (FBRR) 66 FR 31086, June 8, 2001, Vol. 66, No. 111**
Purpose	**Improve public health protection by assessing and changing, where needed, recycle practices for improved contaminant control, particularly microbial contaminants.**
General Description	**The FBRR requires systems that recycle to return specific recycle flows through all processes of the system's existing conventional or direct filtration system or at an alternate location approved by the state.**
Utilities Covered	**Applies to public water systems that use surface water or ground water under the direct influence of surface water, practice conventional or direct filtration, and recycle spent filter backwash, thickener supernatant, or liquids from dewatering processes.**

Public Health Benefits

Implementation of FBRR will result in . . .	‣ **Reduction in risk of illness from microbial pathogens in drinking water, particularly *Cryptosporidium*.**
Estimated impacts of the FBRR include . . .	‣ **FBRR will apply to an estimated 4,650 systems serving 35 million Americans.** ‣ **Fewer than 400 systems are expected to require capital improvements.** ‣ **Annualized capital costs incurred by public water systems associated with recycle modifications are estimated to be $5.8 million.** ‣ **Mean annual cost per household is estimated to be less than $1.70 for 99 percent of the affected households and between $1.70 and $100 for the remaining one percent of affected households.**

Conventional and Direct Filtration

- **Conventional filtration, as defined in 40 CFR 141.2, is a series of processes including coagulation, flocculation, sedimentation, and filtration resulting in substantial particulate removal. Conventional filtration is the most common type of filtration.**

- **Direct filtration, as defined in 40 CFR 141.2, is a series of processes including coagulation and filtration, but excluding sedimentation, and resulting in substantial particulate removal. Typically, direct filtration can be used only with high-quality raw water that has low levels of turbidity and suspended solids.**

Recycle Flows

- **<u>Spent Filter Backwash Water</u> - A stream containing particles that are dislodged from filter media when water is forced back through a filter (backwashed) to clean the filter.**
- **<u>Thickener Supernatant</u> - A stream containing the decant from a sedimentation basin, clarifier or other unit that is used to treat water, solids, or semi-solids from the primary treatment processes.**
- **<u>Liquids From Dewatering Processes</u> - A stream containing liquids generated from a unit used to concentrate solids for disposal.**

Critical Deadlines and Requirements

For Drinking Water Systems

December 8, 2003	**Submit recycle notification to the state.**
June 8, 2004	**Return recycle flows through the processes of a system's existing conventional or direct filtration system or an alternate recycle location approved by the state (a 2-year extension is available for systems making capital improvements to modify recycle location).** **Collect recycle flow information and retain on file.**
June 8, 2006	**Complete all capital improvements associated with relocating recycle return location (if necessary).**

For States

June 8, 2003	**States submit FBRR primacy revision application to EPA (triggers interim primacy).**
June 8, 2005	**Primacy extension deadline - all states with an extension must submit primacy revision applications to EPA.**

What does a recycle notification include?

- **Plant schematic showing origin of recycle flows, how recycle flows are conveyed, and return location of recycle flows.**
- **Typical recycle flows (gpm), highest observed plant flow experienced in the previous year (gpm), and design flow for the treatment plant (gpm).**
- **State-approved plant operating capacity (if applicable).**

What recycle flow information does a system need to collect and retain on file?

- **Copy of recycle notification and information submitted to the state.**
- **List of all recycle flows and frequency with which they are returned.**
- **Average and maximum backwash flow rates through filters, and average and maximum duration of filter backwash process (in minutes).**
- **Typical filter run length and written summary of how filter run length is determined.**
- **Type of treatment provided for recycle flows.**
- **Data on the physical dimension of the equalization and/or treatment units, typical and maximum hydraulic loading rates, types of treatment chemicals used, average dose, frequency of use, and frequency at which solids are removed, if applicable.**

For additional information on the FBRR

Call the Safe Drinking Water Hotline at 1-800-426-4791; visit the EPA web site at www.epa.gov/safewater; or contact your state drinking water representative.

Additional material is available at www.epa.gov/safewater/filterbackwash.html.

Appendix B

Case Studies

Case Studies in this Guidance Manual and Issues They Address

Case Study No.	Treatment/Issue Addressed	Utility Name	Case Study Location	Population Served	Average Annual Treatment Plant (MGD) Production	Source Water	Page	Section Where It is Referenced in the Manual
1	Improving and Optimizing Current Operations	Owenton Water Works and Kentucky American TriVillage	Owenton, Kentucky	<10,000	1	Surface Water (reservoir)	B-5	3.3
2	Decreasing pH	Public Utility District #1	Skagit County, Washington	70,000	12	Surface Water (reservoir)	B-11	3.4
3	Pre-sedimentation	Kansas City Water Services	Kansas City, Missouri	>600,000	240	Surface Water (river, ground water under the direct influence of surface water)	B-19	3.6
4	Switching Coagulants	Hillsborough River Water Treatment Plant	Tampa, Florida	>450,000	100	Surface Water (river)	B-23	3.7
5	Enhanced Coagulation - Problems with Copper Pitting	Washington Suburban Sanitary Commission	Montgomery and Prince Georges County, Maryland	1,600,000	167	Surface Water (rivers)	B-29	3.7
6	Enhanced Coagulation - Managing Radioactive Residuals	Allen Water Filtration Plant	Englewood, Colorado	48,000	8.5	Surface Water (river, creek, diversions)	B-33	3.7

Case Study No.	Treatment/Issue Addressed	Utility Name	Case Study Location	Population Served	Average Annual Treatment Plant (MGD) Production	Source Water	Page	Section Where It is Referenced in the Manual
7	GAC for TOC Removal	Higginsville Water Treatment Plant	Higginsville, Missouri	<10,000	2	Surface Water (reservoir)	B-39	4.1
8	Nanofiltration Membrane Technology for TOC Removal	PBCWUD Water Treatment Plant #9	West Palm Beach, Florida	132,000	27	Ground Water (surficial aquifer)	B-43	4.3
9	Modifying Chloramination Practices to Address Nitrification Issues	Ann Arbor Utilities	Ann Arbor, Michigan	115,000	20	Surface Water (river, wells)	B-51	5.1
10	Ozonation	Ann Arbor Utilities	Ann Arbor, Michigan	115,000	20	Surface Water (river, wells)	B-57	5.2
11	Ozonation and Biological Filtration	Sweeney Water Treatment Plant	Wilmington, North Carolina	75,000	25	Surface Water (river)	B-65	5.2
12	UV Disinfection	Poughkeepsie Water Treatment Facility	Poughkeepsie, New York	75,000	16	Surface Water (river)	B-71	5.3
13	Chlorine Dioxide for Primary Disinfection and Chloramines for Secondary Disinfection	Gulf Coast Water Authority	Texas City, Texas	92,000	12	Surface Water (river)	B-75	5.4

Case Study No.	Treatment/Issue Addressed	Utility Name	Case Study Location	Population Served	Average Annual Treatment Plant (MGD) Production	Source Water	Page	Section Where It is Referenced in the Manual
14	Chlorine Dioxide for Primary Disinfection and Chloramines for Residual Disinfection	Village of Waterloo Water Treatment Plant	Waterloo, New York	<10,000	2	Surface Water (lake)	B-81	5.5

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Case Study #1
Improving and Optimizing Current Operations
Owenton Water Works and Kentucky American TriVillage
Owenton, Kentucky

This case study provides an example of how two small PWSs, both using water treated by the same conventional filtration plant, worked together to change chlorination practices to their existing treatment and operations to reduce TTHM. Reducing TTHM was the primary objective, due to the timing of this work beginning in late 1999 prior to regulatory limits for these systems serving a combined population under 10,000.

Changes described here took place primarily over the first 6 months of 2000 and were made in a series of carefully planned and monitored steps in close consultation with the state regulatory officials and with knowledge of available EPA regulations and guidance. This work has also been successful in reducing HAA5s as these systems completed the first year (2004) in compliance with the 80/60 THM/HAA limits.

Prior to moving the point of chlorination, the following steps were carried out:

1) Enhanced coagulation was initiated at lower pH to improve TOC removal and sodium hydroxide (caustic soda) was added to maintain distribution corrosion control;

2) Potassium permanganate feed to the raw water was optimized to control source water manganese and to provide reliable pre-oxidation in anticipation of moving the chlorine application point; and

3) In-plant chlorine disinfection contact time was assessed and operations revised to increase chlorine retention time in the plant clearwell. This step included trending 12 months of disinfection data in the plant and consultation with the state. The state provided a list of additional source monitoring (microbiological and other related water quality parameters from source through distribution) to be conducted prior to and following the change in chlorine application point.

The point of chlorination was then moved by turning off the chlorine feed to the rapid mix portion of plant treatment and increasing chlorine at the application points just before and after the filters to provide the required residuals in the plant clearwell and through distribution.

This case study is documented in Routt (2004) and Routt and Pizzi (2000). Readers may refer to those references for more details. Updates were also provided for this case study by J. Routt in January 2005.

Introduction

The Owenton City Water Works operates a conventional 1 million gallons per day treatment plant that uses water from an algae-rich reservoir. Approximately half of the water that is produced by the Owenton facility is sold to Kentucky American Water Northern Division (TriVillage), a privately owned water system. Owenton delivers the remainder of the water in its own distribution network. Together, the two systems serve fewer than 10,000 people. However, for several years prior to this work (which began in late 1999), both systems had been regularly issuing state-required health-based public notices due to elevated TTHM.

To define the factors contributing to the elevated DBPs, Kentucky American Water, in cooperation with the City of Owenton, collected water quality data from both systems. These data showed that the most effective solution to the elevated DBPs would be to switch to a source water of higher quality. Switching source waters, however, was understood to be a long-term, expensive project that would require designing and building new intake and transmission facilities. In the meantime, the systems decided to make operational changes to improve water quality before the completion of the new intake and transmission lines.

The Original Treatment Process at the Owenton WTP

The system used a high TOC, high alkalinity source water prone to fluctuating manganese levels. Before treatment changes were made, chlorine was being added at the rapid mix and again at booster stations to provide required free chlorine residuals through the distribution system. The treatment plant was using alum-lime coagulation with a pH of approximately 7.8, and was achieving less than 28 percent TOC removal. This TOC removal efficiency would not meet the Step 1 requirements of the Stage 1 D/ DBPR for the system. In addition, monitoring showed that TTHM levels were elevated leaving the treatment plant and increased substantially with retention time and re- chlorination through the distribution network.

Simultaneous Compliance Issues Faced by the Utilities

The combined systems had high TTHM concentrations and were faced with the challenge of complying with upcoming Stage 1 D/DBPR and Stage 2 DBPR requirements. Priorities and plans had to be clearly set to help ensure ongoing compliance with other regulations that stood to be impacted by treatment changes to reduce DBPs–such as SWTR disinfection and filtered turbidity requirements, LCR corrosion control requirements and TCR microbiological control requirements. To that end, the systems embarked upon a cooperative effort to proceed through steps to improve DBPs for the short term–using existing source water and treatment and distribution facilities–while keeping the multiple regulatory requirements in mind.

Steps Taken by the Utilities

Profiles of TOC removal, TTHM formation, and disinfection were collected through the plant and distribution system. These process profiles showed that TOC was not being effectively removed, and that high levels of TTHM and HAA5 were being formed in the treatment plant.

Treatment changes, therefore, consisted of maximizing TOC removal and optimizing chlorine disinfectant application. Operational changes were made in a phased process over several months, with state approval granted for each step. The results of each step were evaluated before the systems proceeded to the next phase.

Enhancing Coagulation

The removal of TOC was increased by making several relatively simple changes to the coagulation process in the Owenton treatment plant. Coagulation and TOC removal were enhanced by ceasing pre-lime application, and approximately doubling the alum dose to lower the treated water pH to 6.9. The change in coagulation chemicals required addition of a postfiltration caustic feed (sodium hydroxide) to adjust the finished water's pH to 7.6-7.8 for distribution system corrosion control.

In addition, a switch from alum to ferric chloride was made in order to improve the solids handling in the plant's solids-contact upflow clarifier. Ferric chloride was expected to produce good TOC removal with less chemical, and to produce a more stable floc, less prone to upset and carry-over onto filters. These expectations were met.

Changes to the coagulation process roughly doubled the TOC removal and decreased chlorine demand. Chlorine residuals persisted noticeably longer in the distribution system, which allowed the systems to reduce their re- chlorination doses at the master metering points in the distribution system. Levels of TTHM, however, were decreased by only 15 percent. The next step was to evaluate plant disinfection and seek state approval to move the point of chlorination to later in the treatment process.

Converting to Top-of-Filter Chlorination

Prior to moving the chlorination point, the Owenton plant was thoroughly assessed for adequate disinfection contact time. Tracer studies were conducted of the clearwell, which is well-baffled, and operational guidelines were changed to increase the minimum water level in the clearwell which effectively increased the chlorine disinfection contact time with filtered water. This was to offset contact time that would be lost when chlorine application was moved from rapid mix to the top of the filters. Potassium permanganate pretreatment procedures were revised to incorporate regular demand tests to improve dosing accuracy and to reduce chlorine oxidant demand. It was emphasized that, once the point of chlorination was moved to the top of the filter, permanganate would be the only pre-oxidant. Therefore, optimization would be critical to good coagulation of natural organics and to prevent manganese carryover when treating the fluctuating dissolved manganese in the source water.

The state approved the system's proposal to switch to ferric chloride coagulant, followed by post-caustic for corrosion control, and moving the point of chlorination to the top of the filters. The changes were made in sequence and with close supervision and monitoring. The change in point of chlorination was approved with the contingency that additional testing would be conducted before and after the change, in order to verify adequate disinfection and good overall water quality. This additional testing included TOC and organic nitrogen source water monitoring, as well as heterotrophic and total coliform bacteria monitoring through the treatment plant and distribution network.

Optimization of Booster Chlorination

In addition to the changes made at the Owenton treatment plant, both water systems have worked to optimize their distribution systems, and the purchaser, TriVillage, has optimized chlorine doses at the booster stations. The reduction in finished water TOC leaving the Owenton plant has allowed for a reduction in the amount of booster chlorine needed to maintain a residual throughout the distribution system. Both systems have conducted additional flushing and have cleaned and inspected their storage tanks. Since the changes, lead and copper action levels and TCR standards have been met in both distribution systems. The systems continued to conduct extra testing for TOC, DBPs, chlorine residual, and HPCs to track distribution system water quality. In 2004, the TOC and DBP "compliance" testing has replaced the earlier special testing.

Implementation and Operational Issues Faced by the Utilities

Overall, operational changes have gone smoothly. The greatest ongoing operational impacts have been related to enhanced coagulation: an increase in (approximate doubling of) chemical treatment costs, along with a need for increased attention to solids removal from the upflow clarifier and filter backwash settling basins.

Post-filter caustic feed has necessitated cleaning of deposits from filtered water transfer pumps just downstream of the application point. This caustic buildup did not become problematic until 2004 - 4 years after the initiation of caustic feed. However, utilities are advised to watch for caustic clogging in mechanical devises located immediately downstream of caustic application points.

In the summer of 2001, source water dissolved manganese temporarily increased to levels that could not be treated by potassium permanganate alone. The resulting discolored water forced the system to return to minimal prechlorination and, then, to switch briefly to polyaluminum chloride as coagulant. The polyaluminum chloride coagulated well at a higher pH (8.0), which improved potassium permanganate removal of the dissolved manganese and eliminated the need for pre-chlorine. Within a few weeks, the source water manganese levels dropped, and the system returned to ferric chloride coagulation at lower pH. This scenario has not recurred since.

Systems should be extremely careful when switching coagulants to ensure that they maintain consistent particle and pathogen removal. The dosage of new coagulant needed should be carefully calculated and confirmed with up-to-date jar testing using the water to be treated.

Results of the Steps Taken

Since changes were made in May 2000, filtered and distributed water quality compliance has been maintained. TTHM levels have dropped below the 0.080 mg/L standard. Testing has shown that HAA5 levels have been reduced by more than half as well. As of 2004, the first year of compliance TOC testing showed monthly removal ratios ranging from 1.96-2.35 and averaging 2.19 for the year, and the RAAs for THM and HAA5 levels were 74 and 47 ug/L, respectively.

Overall, customers have noticed that their water has improved in clarity and taste of their water, possibly due to the enhanced coagulation, and decreased chlorine demand combined with diligent attention to water quality throughout the system.

Lessons Learned From this Case Study

- Source water testing and the development of treatment plant and distribution system profiles helped the systems identify the factors that were causing DBP formation;
- By adjusting coagulation methods and the point of chlorination, while optimizing distribution operations to optimize booster chlorine use, these small surface water systems succeeded at reducing TTHM and HAA5 in the combined system, even when using a challenging source water;
- Compliance with TTHM and HAA5 standards can be achieved, without negatively impacting other regulatory programs, by implementing a combination of several carefully planned and monitored operational changes; and
- Water quality improvements can be realized with short-term operational changes, and provide information useful in decision-making, pending completion of more costly, time-intensive, long-term modifications.

Further Reading

Readers can find more information about this case study in the following publications:

Routt, J.C. 2004. Lowering DBPs in Combined Systems. *Opflow*. 30(4): 1-7.

Routt, J.C. and N.G. Pizzi 2000. Kentucky-American Water’s Cooperative, Step-wise Process of Assisting Two Small Contiguous Systems in Complying with Pending D/DBP Requirements. In *Proceedings of AWWA Water Quality Technology Conference*.

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Case Study #2
Modifying pH During Chlorination
Public Utility District #1
Skagit County, Washington

This case study provides an example of how a PWS used pH depression to reduce DBPs. The depression of pH via carbon dioxide (CO_2) injection ahead of the flocculation basins also produced the following results:

1) Increased coagulation efficiency and removal of DBP precursors;

2) Increased CT throughout the treatment plant, allowing for reduced chlorine injection; and

3) Increased and stabilized pH levels in the distribution system by increasing the buffering capacity following caustic soda addition.

The information for this case study came from Friedman and Hamilton (1997). Readers should refer to that reference for further information.

Introduction

Public Utility District #1 of Skagit County (the District) is located in the northwest sector of Washington State, approximately 70 miles south of the Canadian border and 70 miles north of Seattle. The District's source of supply is Judy Reservoir, which is fed by several streams originating in the Cultus Mountain watershed in Sedro-Woolley, WA. The District operates a water filtration plant (WFP) designed to provide an original nominal/hydraulic flow of 12/18 million gallons per day (MGD) with an ultimate capacity of 21/36 MGD. Exhibit B.1 provides a summary of typical water quality parameters.

Exhibit B.1 Summary of Historical Source Water Quality Data

Parameter	Units	Range of Values
Conductivity	mhos/cm	30-60
Temperature	°C	1-21
pH	standard units	6.9-7.5
Alkalinity	mg/L as $CaCO_3$	14-16
Hardness	mg/L as $CaCO_3$	8.6-21.6
Dissolved Oxygen	mg/L	9-13
TOC	mg/L	3.0-7.0
Turbidity	NTU	0.25-1.5

In the late 1980s, the District faced several source water quality issues. The TOC in the Judy Reservoir supply ranged from 3 to 7 mg/L, leading to high formation of DBPs upon chlorination. The District was having difficulty meeting CTs year-round, especially during the colder months. The Judy Reservoir supply is soft and poorly buffered, with alkalinity levels between 14-16 mg/L as $CaCO_3$, and the District exceeded the lead action level under the LCR.

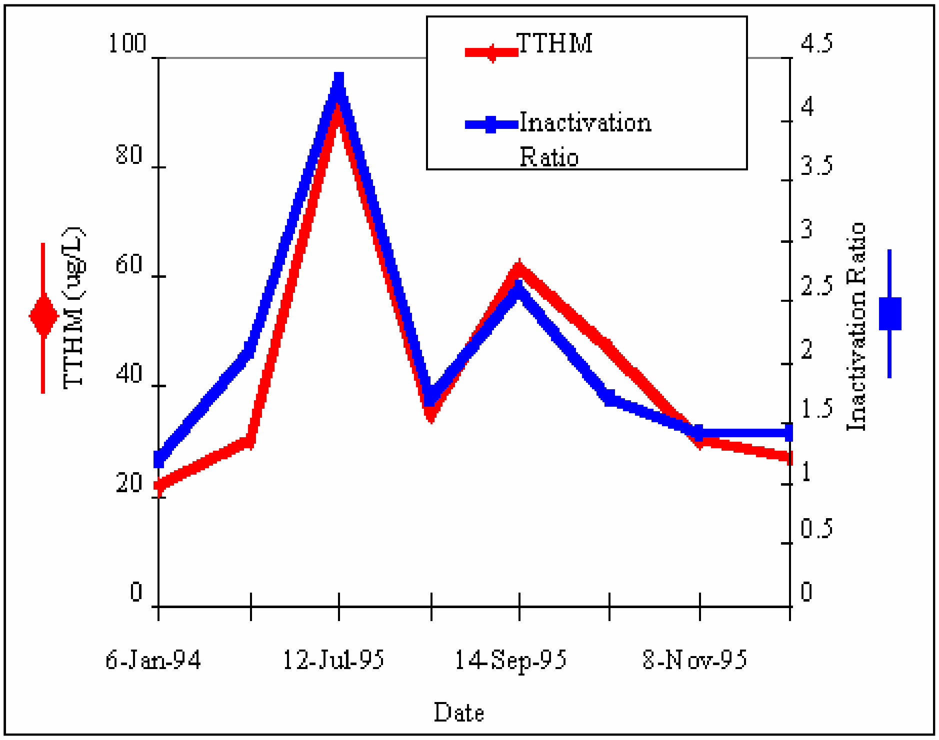
The Original Treatment Process at Judy Reservoir

Before changes were made, initial oxidation/ disinfection was provided by chlorine dioxide, primarily to oxidize manganese which is present in the 0.2-0.3 mg/L range. Coagulants consisting of hybrid aluminum salts and a polyquaternaryamine were used. Direct filtration was conducted with a slight addition of a mild anionic filter aid. The filter media consisted of one foot of silica sand and two feet of anthracite coal. Typical flows were 6000 gpm (8.6 mgd) in the winter and 11,800 gpm (17 mgd) in the summer with 2000 square feet of available filter surface area. Chloramination was used for secondary disinfection.

Simultaneous Compliance Issues Faced by the Utility

The District was having difficulty meeting CTs required by the SWTR. To address this problem, free chlorine was historically applied ahead of the flocculation basins to increase CTs. However, TOC levels in the Judy Reservoir led to high formation levels of DBPs upon chlorination. This situation created difficulty for the District in complying with the Stage 1 D/DBPR. Exhibit B.2 shows the historical relationship between inactivation ratio (calculated CT divided by required CT) and TTHM formation.

Exhibit B.2 Inactivation Ratio vs. TTHM Plant Effluent



Using existing treatment methods, CTs could not be met consistently without significantly increasing DBPs. Thus, a method other than increasing chlorine and contact time was needed to achieve higher inactivation ratios. Methods of decreasing pH levels throughout the treatment train were therefore considered. Because the District used direct filtration (rather than conventional filtration), they were not required to meet TOC removal criteria under the Stage 1 D/DBPR. However, lowering the pH at the beginning of the treatment train would have the added benefit of enhancing coagulation, increasing the removal of DBP precursor materials.

Simultaneously, the District was having difficulty complying with the LCR; the 90th percentile lead level was 0.049 mg/L at a finished water pH of approximately 7.3. The pH was raised to 8.0 but the lead action level was still exceeded. Electrochemical corrosion testing was conducted to compare the corrosion control effectiveness of pH adjustment and orthophosphate addition for lead containing surfaces. The greatest reductions in corrosion rate were observed when the pH was raised to 8.5, or when the pH was raised to 8.0 and 4 mg/L (as PO_4) were added. Due to a number of functional constraints, the District did not want to add phosphates to the water supply. Thus, the decision was made to increase pH to the range of 8.5 to 9.0.

Like most surface water supplies in the Pacific Northwest, the District's Judy Reservoir supply is very soft and poorly buffered. Alkalinity levels are between 14-16 mg/L as $CaCO_3$. To maintain the desired pH range of 8.5 to 9.0 throughout the distribution system, alkalinity increases would also be required.

Steps Taken by the Utility

The District injected CO_2 prior to the flocculation basins in addition to at the end of the treatment train where caustic soda is added. The advantages of adding carbon dioxide ahead of the flocculation basins were three-fold:

1) The associated pH depression increased coagulation efficiency to remove DBP precursors;
2) The associated pH depression increased CTs throughout the treatment plant, allowing chlorine injection to be reduced; and
3) Subsequent pH increases using caustic soda provided finished water with increased alkalinity levels and, increased buffering capacity.

The chemistry of CO_2 is well understood and is used extensively throughout the water and wastewater industry. However, use of CO_2 for WTP process control in the Pacific Northwest was fairly uncommon. The stoichiometry of CO_2 addition in the pH range of 6.0 to 10.0 is outlined below.

$$CO_2 + H_2O \longrightarrow H_2CO_3 \text{ (carbonic acid)}$$
$$H_2CO_3 \longrightarrow H^+ + HCO_3^- \text{ (bicarbonate)}$$

Over the pH range of 6.0-10.0, the dissociation of carbonic acid in water depresses the pH and adds bicarbonate, which is the primary contributor to alkalinity.

CO_2 feed was set up at two locations within the District's treatment facility: 1) ahead of the flocculation basins and 2) at the plant effluent. CO_2 injection began on a trial basis during March, 1995. 24-144 lb/d (2 mg/L) were injected ahead of the flocculation basins (depending on plant flow), and 192 lb/d (3 mg/L) were injected after filtration. The target pH level ahead of the flocculation basin was less than 6.5. Additional CO_2 was required prior to caustic soda addition to raise the alkalinity of the finished water to 25 mg/L as $CaCO_3$.

Results of the Steps Taken

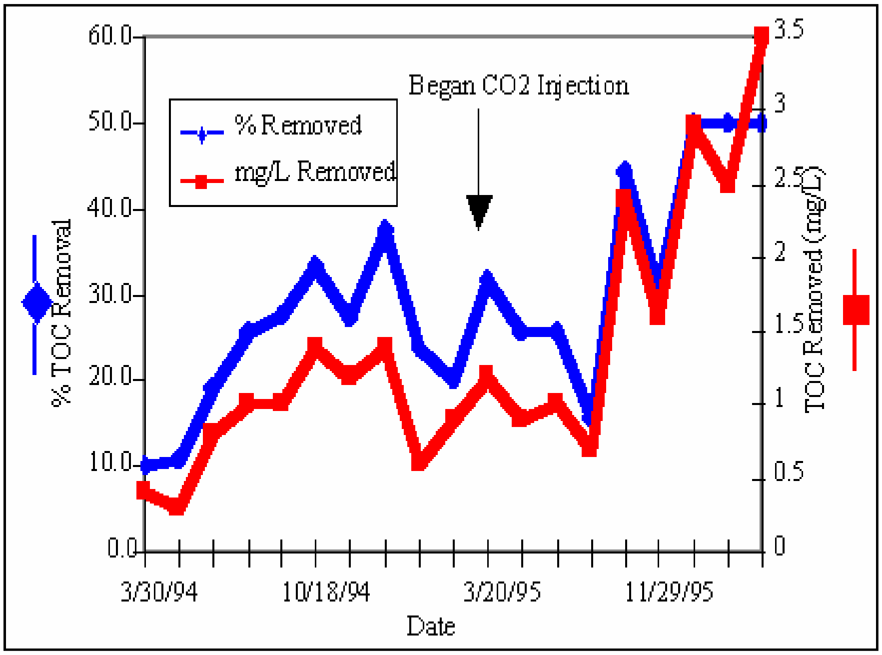
Effects on DBP Formation

With the depression of pH and resulting increased coagulation efficiency, the percent of TOC removal increased from an average of 25 percent to approximately 40 percent. The mass of TOC removed nearly tripled from 1 mg/L to 2.5-3 mg/L. The percent and mass of TOC removed before and after CO_2 injection are shown in Exhibit B.3. Thus, even a small decrease in pH (from 6.9 to 6.6) during coagulation and flocculation has significantly enhanced coagulation.

Exhibit B.3 shows the percent and max of TOC removed after CO_2 injection was initiated in March 1995. During the first few months, CO_2 was fed on a trial basis using a temporary feed system that restricted the amount of CO_2 that could be added. Thus, initial decreases in TOC removal were observed until the system stabilized.

TTHM formation within the treatment train was reduced by approximately 33 percent. Observed decreases in TTHM formation can be attributed to enhanced TOC removal, reduced chlorine levels, and to the fact that less TTHMs are formed at lower pH levels. Prior to CO_2 addition, HAA5 levels in the plant effluent ranged between 40-60 µg/L when TOC levels were between 3-5 mg/L. After CO_2 addition, HAA5 levels in the plant effluent decreased to the range of 35-45 µg/L even though raw water TOC levels were in the range of 5-7 mg/L.

Exhibit B.3 TOC Removal vs. Time



Effects on CT Compliance

CT credit decreases as temperature, disinfectant concentration, and contact time decrease. CT credit using chlorine increases as pH decreases. Since DBP formation was a concern for the District, the best way to increase CT credit without forming additional DBPs was to lower the pH.

It is difficult to show actual improvements in the District's CT compliance as a result of CO_2 addition since disinfectant dosages, plant throughput (i.e., contact time) and temperature vary from month to month. However, the impacts of depressing the pH by 0.5 units are outlined in terms of required chlorine dose and required contact time in Exhibit B.4.

Exhibit B.4 Impacts of CO_2 Injection on CTs

Effect of pH on Required Free Chlorine Dosages		
pH	**Contact Time (min)**	**Required Free Cl_2 (mg/L)**
7.0	82.5	2.0
6.5	82.5	1.67
6.0	82.5	1.41
Effect of pH on Required Contact Time		
pH	**Contact Time (min)**	**Required Free Cl_2 (mg/L)**
7.0	82.5	2.0
6.5	69	2.0
6.0	58	2.0

Thus, the same CT can be achieved with less chlorine. Alternatively, higher flows can be accommodated without increasing chlorine dosages. It should be noted that in addition to considering impacts of reduced chlorine dosages on CT, utilities must consider other drivers for determining chlorine dose, such as the ability to maintain a disinfectant residual throughout the distribution system. Because Skagit PUD#1 chloraminates, they are able to maintain a stable residual despite fluctuations in chlorine dosage at the head of the treatment plant.

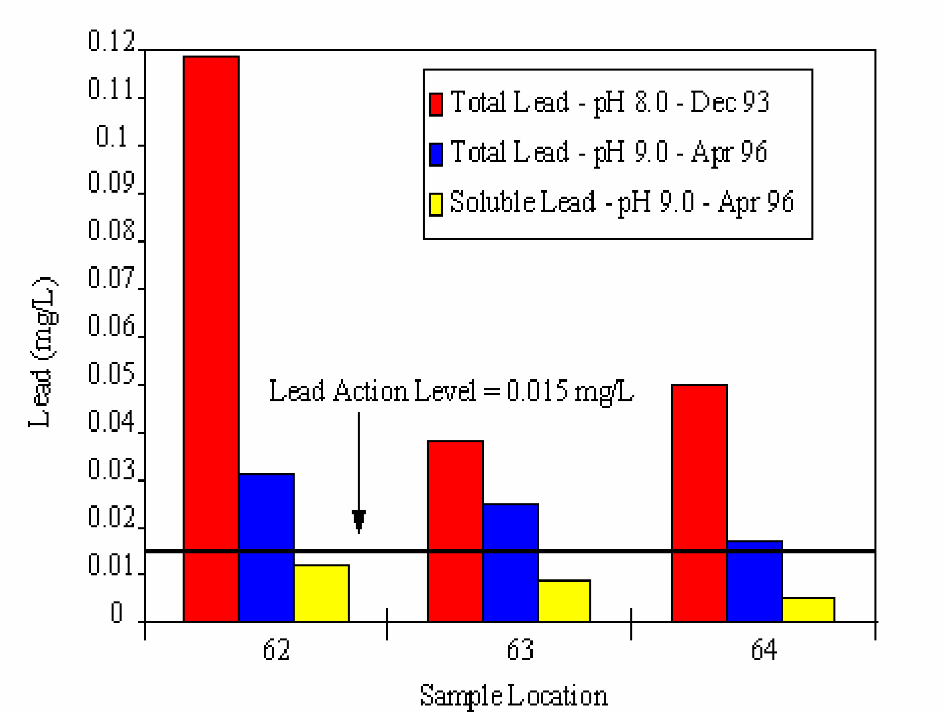
Effects on Corrosion Control Treatment

Distribution system water quality sampling suggested that pH and alkalinity levels are more uniform throughout the system. Alkalinity levels have nearly doubled (from 14 mg/L as $CaCO_3$ to 25 mg/L as $CaCO_3$), resulting in more stable water with respect to pH and corrosion control. Prior to CO_2 injection, the District would raise the pH of the finished water to 8.0, but it would decrease to 7.4 at many locations within the distribution system. Follow-up LCR monitoring conducted by utilities across the U.S. has shown that providing consistent and stable pH/ alkalinity levels can be essential to controlling lead levels at the tap. The District found that nearly a year of CO_2 injection has to pass before pH levels stabilized within the distribution system.

Lead levels at the tap decreased substantially at most of the "high lead" homes in the District. The 90th percentile lead level was 0.004 mg/L during the last round of monitoring conducted in 2003. It is likely that increased alkalinity helped to decrease lead levels by two different mechanisms: 1) providing stabilized pH levels at the tap; and 2) increasing carbonate levels to aid in the formation of more stable lead carbonate passivating films.

A study was undertaken by the District to determine whether elevated lead levels measured at the tap were in the soluble or particulate form. It was found the lead was primarily in the particulate form. When the pH was adjusted to 8.0 without alkalinity adjustment, elevated lead levels were mostly due to particulate lead (particulate being the difference between total and soluble lead), suggesting that stable lead carbonate films were not forming. After the pH was further increased and the alkalinity was doubled, total lead concentrations decreased as shown for three sampling locations in Exhibit B.5. Although lead solubility theoretically decreases as pH increases to a maximum of 9.5, alkalinity adjustment may also be necessary to address the particulate lead fraction.

Exhibit B.5 Total vs. Soluble Lead



Implementation and Operational Issues Faced by the Utility

CO_2 does not solubilize instantaneously, and therefore a pressurized solution feed system was required. In this system, the CO_2 is injected to a pressurized side stream forming carbonic acid. The carbonic acid solution is readily solubilized by the receiving water and is injected directly into the pipeline.

Chemical costs for caustic soda doubled once CO_2 was injected since twice as much caustic was required to raise the pH to 8.5-9.0. Considering the multiple benefits the District is experiencing, a chemical cost increase of $30,000 per year or $10 per million gallons treated was relatively inexpensive. The capital cost of the permanent CO_2 system was $15,000 (1996 dollars).

Lessons Learned From this Case Study

- It is possible to achieving both greater Ct and TOC removal by reducing pH during treatment;
- pH reduction can in some cases be achieved through CO_2 injection; and
- CO_2 injection at multiple locations during treatment may enhance benefits compared to injection at the end of treatment only for pH control purposes.

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Case Study #3
Pre-sedimentation
Kansas City Water Services
Kansas City, Missouri

This case study provides an example of how Kansas City's existing pre-sedimentation basins may help to achieve compliance with the upcoming regulations.

Kansas City's pre-sedimentation basins were constructed prior to development of the DBPRs and ESWTRs, but still provided a benefit with respect to regulatory compliance. These pre-sedimentation basins have the potential to assist in providing the following benefits:

- TOC reduction required under the Stage 1 D/DBPR due to coagulation in the basins;
- Turbidity reduction necessary for compliance with the ESWTR; and
- 0.5-log treatment credit for removal of *Cryptosporidium* (if needed to comply with the LT2ESWTR.

Under the LT2ESWTR, systems are required to collect their source water samples prior to chemical treatment, such as coagulation, oxidation, and disinfection, for the purpose of determining their bin classification. Kansas City applies treatment chemicals (coagulants, potassium permanganate, lime) to the pre-sedimentation basins and must therefore collect samples for LT2ESWTR monitoring prior to the basins. However, Kansas City is eligible for a 0.5-log *Cryptosporidium* treatment credit for the pre-sedimentation basins if the basins can achieve a monthly mean reduction of 0.5 log in turbidity.

Both the LT2ESWTR sampling location and the Stage 2 D/DBPR treatment plant point-of-entry are considered to be the influent to the pre-sedimentation basins. However, simultaneous compliance issues associated with pre-sedimentation basins include the potential for algae blooms, which can increase disinfection by-product formation at the plant effluent.

This case study was developed using information available from staff at Kansas City Water Services.

Introduction

The Kansas City, Missouri drinking WTP, which was originally constructed in the 1920s, is rated for 240 MGD. The source water comes from the Missouri River and wells under the influence of the Missouri River. The treatment process involves pre-sedimentation, excess lime softening, recarbonation, filtration, and stabilization.

Due to the turbidity levels of the Missouri River, the pre-sedimentation basins are a critical step in the City's WTP processes. The turbidity of the untreated source water is quite variable, averaging 114 nephelometric turbidity units (NTU) in 2002, 185 NTU in 2003, and 318 NTU in 2004. The untreated water turbidity can exceed 5,000 NTU. The turbidity of the untreated source water was even higher and more variable when the plant was built. However, the construction of several upstream dams during the 1960's resulted in lower turbidity levels at the City's intake. In addition, the pre-sedimentation basins serve to reduce the amount of solids entering the softening process.

The plant was constructed well before the Safe Drinking Water Act (SDWA) and subsequent drinking water regulations came into effect. Therefore, the pre-sedimentation basins were not designed to meet compliance issues as much as they were needed as part of the water treatment process. However, as the treatment regulations evolved, the pre-sedimentation basins helped the plant meet new regulations.

The Treatment Process at the Kansas City, Missouri WTP

Today there are 6 pre-sedimentation basins, each with a detention time of about 4 hours at 40 MGD. Each pre-sedimentation basin is approximately 200 feet in diameter and has an 80-foot diameter fiberglass ring installed that is approximately half the height of the basin. This fiberglass ring serves as a mixing area for the coagulation chemicals to react. There are four mixers in each pre-sedimentation basin. These mixers and the capability for chemical injection were added to the pre-sedimentation basins in the 1970s. Lower source water turbidity levels resulted in reduced solids loading to the pre-sedimentation basins and increased colloidal materials, impacting the efficiency of the pre-sedimentation basins for removing turbidity. Therefore, the mixing areas and chemical feed capabilities were added. However, the solids removal capacity of the basins remained the same.

Role of Pre-sedimentation Basins in Regulatory Compliance

Kansas City's pre-sedimentation basins could be used to lower turbidity as part of compliance with the Surface Water Treatment Rules (SWTRs). Additionally, compliance with the Stage 1 D/DBPR requires removal of TOC from source water to reduce the formation of DBPs. Pre-sedimentation basins may serve to remove a portion of the TOC. Kansas City can receive a 0.5-log *Cryptosporidium* reduction credit for the pre-existing pre-sedimentation basins because the basins may assist in removing *Cryptosporidium* from the source water. Kansas City is required to monitor the influent of their pre-sedimentation basins to determine their *Cryptosporidium* bin classification.

Simultaneous Compliance Issues Faced by the Utility and Steps Taken

Algae may grow in the pre-sedimentation basins, which could contribute additional NOM and result in the formation of DBPs, affecting compliance with the DBP Rules. Kansas City has managed to avoid this simultaneous compliance issue by minimizing algae blooms through potassium permanganate addition in the pre-sedimentation basins. Additionally, the velocity of the water in the pre-sedimentation basins is kept high by the mixers. In the rare instance that algae is observed, it is minimal and typically resides around the sides of the pre-sedimentation basins. Additionally, the pre-sedimentation basins are followed by an excess lime softening step, during which pH levels are raised above 10 units, reducing the potential for algae growth in this step.

Implementation and Operational Issues Faced by the Utility

The pre-sedimentation basin improvements allow the plant to add a variety of treatment chemicals to control turbidity of the pre-sedimentation basin effluent. The water plant has the capability of feeding ferric sulfate, polymer, and potassium permanganate to these basins. The turbidity of the pre-sedimentation basin effluent is controlled based on the economics of the treatment plant operations. By adding different coagulation chemical concentrations and combinations, the turbidity exiting the pre-sedimentation basis can be reduced to below 10 NTU. The plant uses factors such as lime dose requirements to determine the optimal treatment in the pre-sedimentation basins. This is because higher turbidity water entering the softening basins usually has more colloidal material, which in turn requires more lime to provide the desired softening because of the competing reactions between the charges stabilizing the colloids and the calcium carbonate precipitation process. Thus, the cost of the coagulant dosage to obtain a certain turbidity from the basins is compared to the cost of the lime required to provide the desired softening and an economic balance is found.

The plant reports that 80-90 percent of the time, potassium permanganate is sufficient for addressing operational issues such as taste and odor control and turbidity control. The remainder of the time, ferric sulfate is able to maintain the plant’s operation.

To receive a treatment credit for *Cryptosporidium* removal under LT2ESWTR (if needed), Kansas City will need to evaluate the effectiveness of the dosages in reducing turbidity, and assure that a monthly mean reduction of 0.5-log turbidity is achieved to receive the 0.5-log *Cryptosporidium* treatment credit.

Lessons Learned From this Case Study

The following lessons were learned from Kansas City’s experience with pre-sedimentation basins:

- The pre-sedimentation basins reduce the effects of large and variable turbidity episodes;

- Improving the pre-sedimentation basins to incorporate chemical treatment and mixing allowed the pre-sedimentation basins to become more useful in water treatment operations by allowing the plant to control turbidity entering the softening basins as well as assisting in removing TOC and DBP precursors;

- The potential drawbacks of pre-sedimentation basins such as increased NOM from algae are minimized through operations; and

- Utilities that apply treatment chemicals to their pre-sedimentation basins will need to designate a sampling location prior to the pre-sedimentation basins for *Cryptosporidium* monitoring under the LT2ESWTR. This location may be the same as the point of entry already used for compliance with other regulations.

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Case Study #4
Switching Coagulants
Hillsborough River Water Treatment Plant
Tampa, Florida

This case study describes how a system could simultaneously comply with the TOC removal requirements of the Stage 1 D/DBPR and the turbidity removal requirements of the IESWTR. Enhanced coagulation is a best available technology (BAT) for TTHM precursor removal for the Stage 1 D/DBPR.

Introduction

The City of Tampa, Florida, operates a 100 MGD conventional treatment plant (the Hillsborough River Water Treatment Plant, HRWTP). The HRWTP uses the Hillsborough River as its source water. The plant, built in 1924, currently serves over 450,000 people. In 1991, it switched from enhanced coagulation with alum to enhanced coagulation with ferric sulfate. The influent surface water has high TOC and is subject to large seasonal variations. By switching coagulant, the HRWTP's operators expected to satisfy requirements of the Stage 1 D/DBPR. They had investigated the feasibility of enhanced coagulation with ferric sulfate before the Stage 1 D/DBPR became a regulatory requirement. They found that enhanced coagulation with ferric sulfate not only increased TOC removal significantly, but also reduced turbidity levels in the finished water.

A summary of the influent water quality is provided in Exhibit B.6.

Exhibit B.6 Influent Water Quality at HRWTP

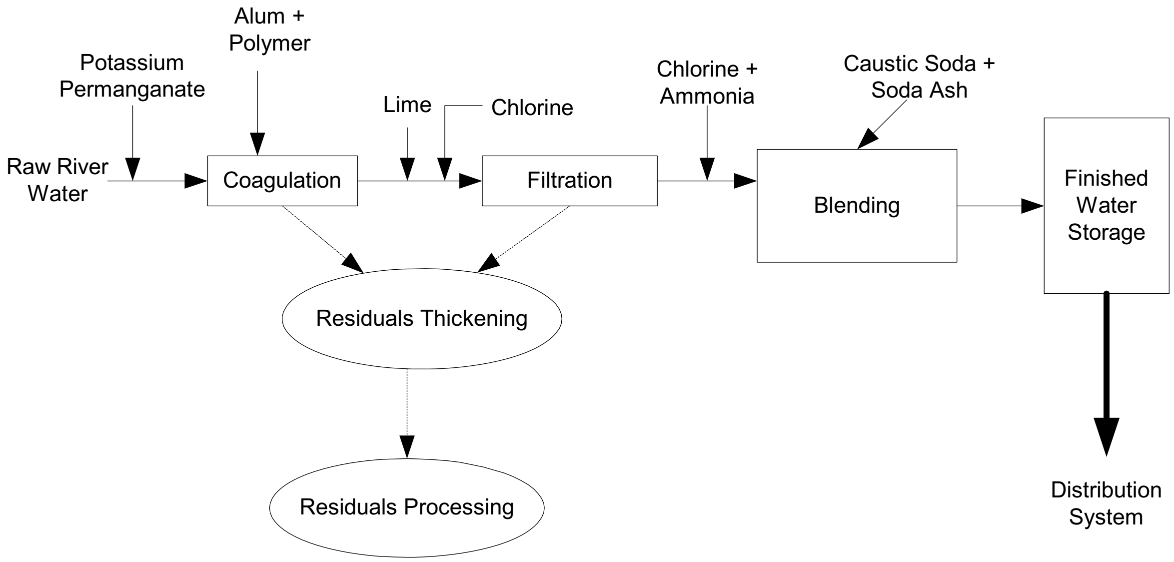
Water Quality Parameters	Influent[1]
TOC (mg/L)	
Minimum	4.3
Average	13
Maximum	26
Turbidity (NTU)	
Minimum	1.2
Average	2.1
Maximum	40
pH	
Minimum	6.8
Average	7.6
Maximum	8.5
Alkalinity (mg/L as $CaCO_3$)	
Minimum	42
Average	93
Maximum	143

Notes: 1. Data from an Information Collection Rule (ICR) sample collection from July 1997 - December 1998

The Original Treatment Process at HRWTP

Exhibit B.7 shows a schematic of the treatment process at HRWTP prior to converting to ferric sulfate. Raw water was treated with potassium permanganate for taste and odor control. Enhanced coagulation was implemented using alum (range of alum dose = 50 - 200 mg/L, average dose = 120 mg/L), at an average pH of 5.7 (range 4.9 - 6.6). An organic polymer was added to enhance the flocculation process. Primary disinfection was attained by applying chlorine just prior to the filters. After filtration, more chlorine and ammonia were added to form chloramines for residual disinfection. The pH of the finished water was increased to around 7.6 with caustic soda and soda ash in the blending chamber, to meet a Langelier Index goal of +/-0.2.

Exhibit B.7 Treatment at the HRWTP Prior to Implementing Enhanced Coagulation



Simultaneous Compliance Issues Faced by the Utility

In order to reduce DBP precursors and TTHM and HAA5 concentrations, the City of Tampa decided to switch to enhanced coagulation with ferric sulfate, enhancing TOC removal and consequently lowering the DBP formation potential.

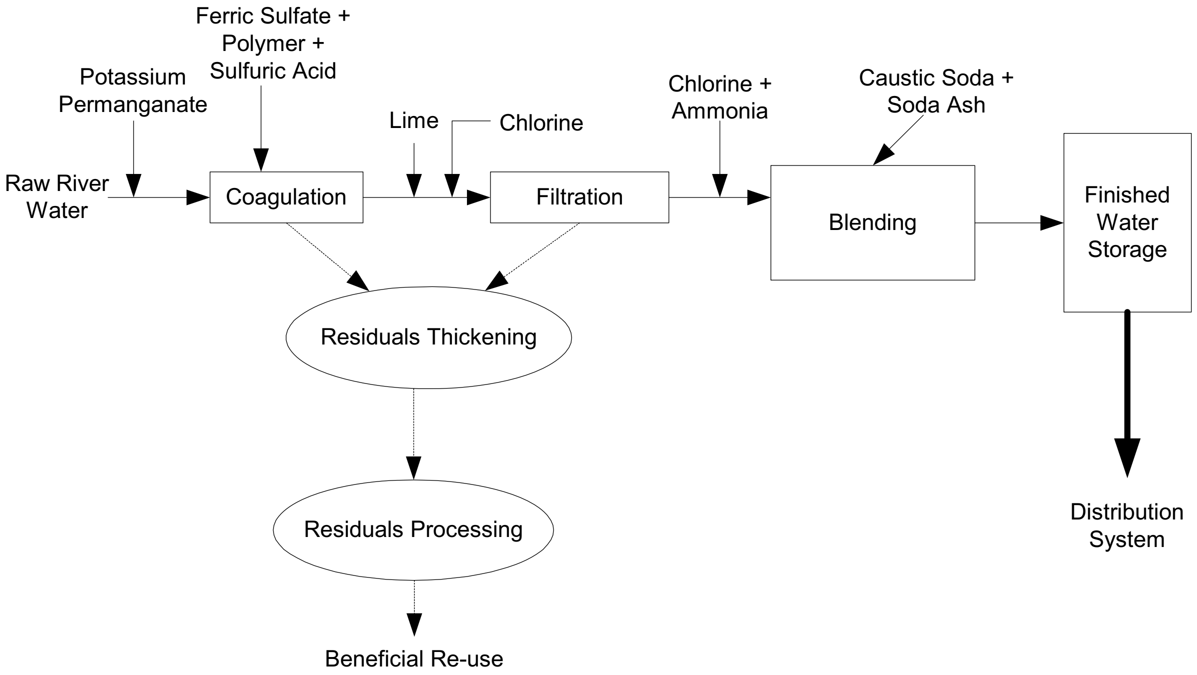
Successfully enhancing coagulation to improve TOC removal can affect particle and pathogen removal effectiveness. The system was concerned that, at lower pH, the higher coagulant dose conditions for enhanced coagulation could result in particle re-stabilization and an increase in settled water turbidity, leading to non-compliance with the IESWTR. Increased settled water turbidity could also impact the system's ability to receive *Cryptosporidium* removal credit for enhanced filter performance. Variability in source water quality presented a further challenge to the operators who were attempting to optimize particle and TOC removal with a new coagulant.

Steps Taken by the Utility

Tampa implemented enhanced coagulation with ferric sulfate to improve TOC removal. At the same time, it applied BMPs to ensure that filter effluent turbidity would not be adversely affected. These included flow-pacing the coagulant feed and conducting additional jar tests to ensure that coagulant overdosing did not occur.

Exhibit B.8 shows a schematic of the treatment process at HRWTP after the system changed to enhanced coagulation with ferric sulfate. Raw water continues to be treated with potassium permanganate for taste and odor control. Enhanced coagulation uses ferric sulfate (range dose = 40 - 300 mg/L, average dose = 140 mg/L), at an average pH of 4.0 (range 3.5 - 4.8). The low coagulation pH is attained by adding sulfuric acid. An organic polymer is added to enhance the flocculation process. The settled water is treated with lime for partial pH adjustment. The residuals are thickened and then pumped to a residuals processing facility for further dewatering, processing, and disposal. Primary disinfection is attained by adding chlorine to the settled water to produce a free residual of 1-2 mg/L just prior to the filters. After filtration, ammonia and chlorine are added to form chloramines. The finished water combined disinfectant residual ranges from 3 - 4.5 mg/L of monochloramine. The pH of the finished water is adjusted to around 7.6 with caustic soda and soda ash in the blending chamber, to meet a Langelier Index goal of +/-0.2.

Exhibit B.8 Treatment at the HRWTP After Implementing Enhanced Coagulation



To ensure that excessive coagulant dosing doesn't occur, the operators check the coagulant dose regularly with jar tests. The operators also ensure that coagulant feed is flow paced. These practices help ensure that turbidity requirements are not violated.

Results of the Steps Taken

- TOC removal - Finished water TOC removal with enhanced alum coagulation ranged from 21 to 50 percent. For enhanced coagulation with ferric sulfate, TOC removal ranges from 70 to 88 percent, with an average of 81 percent. This is well beyond the minimum TOC removal requirements of the Stage 1 D/DBPR (based on the source water TOC and alkalinity concentrations). Influent and effluent water quality is shown in Exhibit B.9. Thus, enhanced coagulation with ferric sulfate is much more effective than enhanced coagulation with alum for removing DBP precursors;

- TTHM reduction - Before the changes in the coagulation practice, the finished water TTHM ranged from 27 - 111 μg/L, with an average of 59 μg/L (Exhibit B.9). After the treatment modifications (from July 1997 through December 1998), the finished water TTHM ranged from 47 - 67 μg/L, with an average of 60 μg/L. Enhanced coagulation with ferric sulfate seems more effective than coagulation with alum at removing DBP precursors (i.e., TOC), when the raw water is high in TOC. This is reflected by the lower maximum level of TTHM measured after treatment modifications (i.e., the maximum trihalomethane (THM) concentration was reduced from 111 to 67 μg/L). The new treatment approach reduced THMs by increasing TOC removal and chlorinating at a lower pH. Implementing enhanced coagulation with ferric sulfate has enabled HRWTP to achieve compliance with the Stage 1 TTHM MCL of 80 μg/L; and

- Turbidity - As can be seen clearly from Exhibit B.9, enhanced coagulation with ferric sulfate was more effective than alum coagulation at reducing turbidity in the finished water. Enhanced coagulation with ferric sulfate was able to achieve the IESWTR turbidity requirements more easily and consistently.

Exhibit B.9 Finished Water Quality Before and After Implementing Enhanced Coagulation with Ferric Sulfate

Water Quality Parameters	**Influent[1]**	**Finished Water**	
		Before implementing Enhanced Coagulation[2]	**After implementing Enhanced Coagulation[3]**
TOC (mg/L)			
Minimum	4.3	1.8	1.6
Average	13	6.2	2.9
Maximum	26	8.9	5.1
Turbidity (NTU)			
Minimum	1.2	0.04	0.04
Average	2.1	0.32	0.11
Maximum	40	1.13	0.28
pH			
Minimum	6.8	7.1	7.2
Average	7.6	7.6	7.6
Maximum	8.5	8.2	7.7
Alkalinity (mg/L as $CaCO_3$)			
Minimum	42	80	48
Average	93	122	92
Maximum	143	187	125
TTHM (μg/L)			
Minimum	NA	27	47
Average		59	60
Maximum		111	66
HAA5 (μg/L)			
Minimum	NA	NDC	32
Average			47
Maximum			66

Notes:
1. Data from ICR sample collection from July 1997 - December 1998
2. Data collected for calendar year 1990.
3. Data collected for calendar year 1997; ICR data from July 1997 - December 1998 was used for organic analysis.
4. NDC = No Data Collected
5. NA = Not Applicable

Implementation and Operational Issues Faced by the Utility

- Operator training and start-up - It took around 6 months for the operational staff to be comfortable with implementing enhanced coagulation, and nearly a year for the treatment plant to operate like an integral unit. The treatment strategy did not significantly change the operational needs of the plant and no additional staff were added;

- Controlling manganese - The only major problem experienced in implementing the treatment modification was the control of manganese. The lower pH required for enhanced coagulation with ferric sulfate, relative to alum coagulation, allowed dissolved manganese to pass through the filters. The issue was resolved by maintaining the pH on top of the filters at greater than 6.0; and

- Corrosion due to acid addition - The addition of sulfuric acid promoted corrosion in the rapid-mix chamber at the feed diffuser. The problem was resolved when the utility found a suitable coating for their rapid-mix chamber. The coating used was a two-part commercial membrane applied at 60 wet mils, using an air-supplied mastic air gun. After application, the coating required a 7-day curing period before the basin could be put back into service. The settling basins were epoxy-coated and did not experience any corrosion.

Lessons Learned From this Case Study

- Enhanced coagulation with ferric sulfate can achieve the multiple objectives of increased TOC removal and improving reductions in finished water turbidity without significantly changing the operational needs of the plant; and

- One key to successfully implementing enhanced coagulation is to ensure that excessive coagulant dosing does not occur. This results in turbidity breakthrough at the filters, resulting in potential non-compliance with the IESWTR. One way to achieve this is by conducting additional jar tests and flow-pacing the coagulant feed when plant water flows are variable.

Case Study #5
Enhanced Coagulation - Problems with Copper Pitting
Washington Suburban Sanitary Commission
Montgomery and Prince Georges County, Maryland

This case study provides an example of negative effects that could possibly be caused by enhanced coagulation. Washington Suburban Sanitary Commission (WSSC) changed their coagulation process to reduce filtered water turbidity. This was implemented prior to development of the Stage 1 D/DBPR and, therefore, not optimized to meet associated requirements. However, WSSC's experience indicates that coagulation improvements might have had unintended results in the distribution system. After alterations were made to WSSC's coagulation process, WSSC customers began reporting pinhole leaks in their copper piping, possibly caused by a combination of factors. The utility has been unable to determine the exact cause of the pinhole leaks. In this case study, the primary concerns relate to compliance with:

- LCR
- DBP Rules

While this treatment was implemented prior to the DBP Rules, it does indicate a potential problem associated with implementing the Stage 1 D/DBPR's required treatment technique using enhanced coagulation.

This case study was developed using information available from staff at the WSSC and from their customer care Web site detailing this issue (http://www.wsscwater.com/copperpipe/pinholescroll.cfm). The cause of pinhole leaks in WSSC's system continues to be under investigation.

Introduction

The WSSC provides drinking water to 1.6 million people in suburban Maryland. WSSC relies on two rivers, the Potomac and Patuxent, to supply an average of 167 MG per day. Both river supplies are treated at separate filtration plants. The Potomac plant treats river supply while the Patuxent plant treats water from a reservoir system. In the mid-1990s, WSSC made treatment changes at the Potomac plant to enhance filtration performance, including changing filtration media and changing coagulant, from ferric chloride to polyaluminum chloride. During the 1990s, coagulant doses were increased slightly at the Patuxent plant, which used alum most of the time, occasionally switching to ferric chloride during the winter.

The primary reasons WSSC made these treatment changes were:

- Prevention of waterborne pathogen outbreaks - A large-scale cryptosporidiosis outbreak occurred in Milwaukee, Wisconsin in 1993. The outbreak coincided with elevated effluent turbidity levels. Studies of the causes and prevention methods indicated that coagulation and filtration performance are critical in preventing the entry of *Cryptosporidium* to the distribution system; and

- Partnership for Safe Water - This is an industry program, supported by EPA and AWWA, that focuses on protecting drinking water customers from microbial contaminants. WSSC has participated in this program that includes meeting stringent criteria for turbidity in filtered drinking water.

While WSSC's coagulation changes were not optimized for compliance with the Stage 1 D/DBPR, WSSC did observe lower TOC levels in effluent at the Potomac WTP.

The Original Treatment Process at WSSC's WTPs

Both the Potomac and Patuxent Treatment Plants include similar treatment processes:

- Coagulation and flocculation
- Sedimentation
- Filtration
- Fluoridation
- Lime addition for corrosion control
- Chlorination

Simultaneous Compliance Issues Faced by the Utility

In 1998, WSSC began receiving complaints from customers that pinhole leaks were developing in their copper piping. As of December 2004, almost 5,500 customers have reported this problem. Pinhole leaks have occurred in areas served by both drinking water supply sources. WSSC has collected data on pinhole leaks from customers and these trends have been apparent:

- Many pinhole leaks are in cold water horizontal copper piping
- Many leaks are located in older portions of service area
- Almost 80 percent of leaks have occurred in homes built before 1970

In 2000, WSSC formed a task force to study the pinhole leaks and possible causes. The task force included WSSC staff, copper and plumbing industry experts, and corrosion experts. The researchers conducted bench-scale experiments with copper piping and simulated drinking water and determined that a combination of high pH, aluminum solids, and chlorine levels, and no remaining NOM caused significant pitting on copper piping in about one month (Marshall, Rushing and Edwards 2003).

NOM present in drinking water supplies is a DBP precursor and is typically removed through filtration or coagulation. TOC levels usually correspond to the presence of NOM in drinking water. The presence of NOM in the distribution system was previously thought to prevent, to some extent, corrosion of piping materials, such as cement, iron, and copper. The research by Marshall, Rushing and Edwards (2003) contradicts previous understanding of NOM’s role in copper corrosion.

Water quality conditions in WSSC's distribution system that may have contributed to pinhole leaks in copper piping include:

- Aluminum - Since 1995, both treatment plants have used an aluminum-based coagulant. Finished water aluminum levels are relatively low. The average Potomac WTP residual levels range from 0.046 mg/L to 0.060 mg/L, and at Patuxent WTP, which recently switched from alum to polyaluminum chloride, average effluent aluminum levels are 0.030 mg/L (Edwards et al. 2004). In comparison, the national average for effluent aluminum levels is 0.090 mg/L. Sampling in WSSC's distribution system indicated that aluminum levels increased after treatment to levels higher than 0.065 mg/L total aluminum. Researchers indicate that high aluminum samples were collected in areas near recently cleaned or re-lined piping (Edwards et al. 2004). A forensic analysis of WSSC failed copper piping showed that aluminum deposits were frequently present (Marshall, Rushing and Edwards 2003);

- Chlorine - WSSC, like the majority of utilities, uses chlorine to provide a disinfectant residual in the distribution system;

- pH - WSSC increases the pH of water entering their system during the treatment process for corrosion control. Water from the Potomac WTP has a pH of about 7.5 in the distribution system. Until recently, the Patuxent WTP had a pH of about 8.2 in the distribution system (now adjusted to about 7.5 since orthophosphate addition began); and

- TOC - The Potomac WTP achieves approximately 40 percent TOC removal, which is a slight increase since the coagulant and filter media change. Patuxent reservoir water has a lower level of NOM, with treated water TOC levels below 2 mg/L. TOC removal at the Patuxent WTP has not changed.

StepsTaken by the Utility

In late 2003, WSSC implemented orthophosphate addition to both treatment plants. Addition was phased in slowly with the dose reaching a level of 1 mg/L (as PO_4) after 4 to 5 months. This gradual increase was recommended by WSSC's operations staff to limit the potential for discolored water problems caused by phosphates forming comples with iron, making it more soluble. In pilot-testing, orthophosphate effectively reduced pinhole leak activity. WSSC participated in a state-wide task force that surveyed utilities regarding pinhole leaks. WSSC also contacted the EPA regarding the pinhole leak issue and research findings that removal of NOM, as required in the DBP Rules, may promote pinhole leaks in certain waters. Finally, WSSC has worked to educate the public on this topic.

Results of the Steps Taken

Overall, the utility is receiving fewer pinhole leak reports from their customers and area plumbers have indicated that they are seeing fewer pinhole leaks. It will take more time before WSSC can conclusively determine whether orthophosphate has addressed the problem.

Implementation and Operational Issues Faced by the Utility

WSSC experienced the following issues when implementing orthophosphate addition:

- Increased wastewater phosphorus resulted in increasing cost for wastewater treatment;
- WSSC investigated the potential for orthophosphate addition to increase discolored water complaints due to iron release from unlined cast iron mains; and
- During summer conditions, turbidity of finished water (i.e., following post-filter lime addition) has increased occasionally after orthophosphate addition. WSSC is still investigating the cause.

Lessons Learned From this Case Study

- Switching coagulant may have unintended consequences on water quality;
- The role of NOM in copper corrosion control needs to be better understood by the drinking water industry;
- The synergistic effects of chlorine and aluminum at pHs that have been optimized for corrosion control also need to be better understood by the drinking water industry. These interactions can be exacerbated for utilities that use free chlorine; and
- Pilot-scale and/or electro-chemical testing for determining the impacts of chemicals on corrosion control were useful in identifying an appropriate solution.

References

Edwards, M., J.C. Rushing, S. Kvech, and S. Reiber. 2004. Assessing copper pinhole leaks in residential plumbing. *Water Science and Technology*. 49(2): 83-90.

Marshall, B., J. Rushing, and M. Edwards. 2003. Confirming the role of aluminum solids and chlorine in copper pitting corrosion. In *Proceedings of AWWA Annual Conference*. Denver: AWWA.

Rushing, J.C. and M. Edwards. 2002. Effect of aluminum solids and chlorine on cold water pitting of copper. In *Proceedings of AWWA Water Quality Technology Conference*.

Case Study #6
Enhanced Coagulation - Managing Radioactive Residuals
Allen Water Filtration Plant
Englewood, CO

This case study presents a discussion of a system's options for disposing of radioactive residuals resulting from enhanced coagulation. Enhanced coagulation is practiced at the system to meet the requirements of the Stage 1 D/DBPR. Uranium is naturally occurring in the City's source water, but radionuclide levels in the raw water do not warrant treatment for removal. The radionuclides become concentrated in the residuals as a result of the enhanced coagulation process at levels that require special considerations for regulatory approval of sludge disposal.

Introduction

The City of Englewood Allen WFP is a conventional treatment plant with an average treated flow of 8.5 mgd (design flow of 28 mgd) to serve a population of 48,000 people. The primary raw water supply comes from surface sources, including the South Platte River, Bear Creek, and water sources diverted from the Western Slope of Colorado. The plant treatment processes include addition of potassium permanganate, coagulant, and coagulant aid to the pipeline ahead of the rapid mix. Mixing is followed by three-stage tapered flocculation and settling using lamella inclined plates. The water passes through GAC filters prior to chlorine addition. Chlorine contact time is obtained in the clearwell and ammonia is added after the clearwell for chloramine disinfectant residual in the distribution system. Sedimentation sludge and filter backwash water are dewatered by belt press and the filtrate is sent to the backwash settling lagoon along with the waste backwash water. Decant from the backwash settling lagoon is returned to the North Reservoir to be recycled to the head of the plant. Recycle goes into the washwater lagoon (aka backwash settling lagoon) which overflows to an 80 million gallon reservoir that is used sparingly as source water as it is blended with raw water drawn from other sources. The approximate recycle return flow is 1.5%. Treatment includes settling of solids in the lagoon and in the reservoir.

Exhibit B.10 presents source water and finished water quality details. A process schematic is shown in Exhibit B.11.

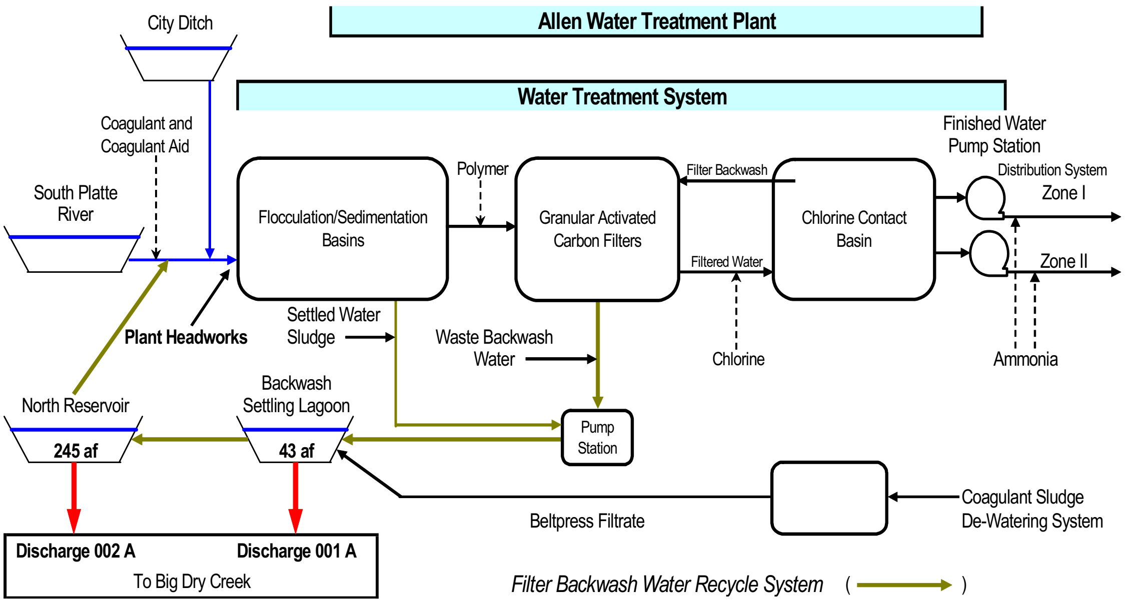
Exhibit B.10 Typical Water Quality Parameters at Allen WFP

Water Quality Parameter	Raw Water	Treated Water
Turbidity (NTU)	1.0 - 12	0.10 - 0.24
pH (SU)	7.9 - 8.7	7.6 - 8.4
TOC (mg/L)	3.5 - 5.0	2.6 - 3.75
Alkalinity (mg/L as CaCO3)	55 - 170	55 – 150
Barium (mg/L)	*	0.048
Selenium (ug/L)	*	0.0077
Alpha Emitters (pCi/L)	34 + 5	7.8 + 3.3
Beta/Photon Emitters (pCi/L)	*	10 + 5
TTHM (ug/L)	*	34 – 55
HAA5s (ug/L)	*	3 – 21

* If available, levels present in raw water will be added to next draft.

The Allen WFP practices enhanced coagulation to comply with the Stage 1 D/DBPR by the addition of alum with typical doses of 40 - 60 mg/L of alum. Based on the average plant flow, the production rate of residuals would be expected to be 1632 lb/day or 302 cy/yr. Recently (2002-2004), residuals production from the backwash pond is approximately 1600 cy/yr. The current large volume may be a result of catching up on previous years' storage. City employees are processing residuals from March to November to make sure the backwash pond does not exceed its capacity.

Exhibit B.11 Allen Water Filtration Plant Schematic



Residuals Management Prior to Enhanced Coagulation

The City of Englewood has historically disposed of water treatment residuals by land applying dried residuals at the City golf course. These residuals were mixed with fill dirt (2:1 ratio fill to residuals) for berm construction with grass cover. This procedure met the requirements of the Colorado Department of Health and Environment (CDPHE) with respect to the state's solid waste regulations and the hazardous/radioactive material regulations. Residuals disposal facilities in Colorado must comply with all Colorado health laws and with CDPHE regulations and standards. Acceptance criteria for solid waste disposal include:

- WFP residuals containing any free liquid cannot be accepted for disposal;
- WFP residuals with a pH less than 6.0 cannot be accepted for disposal; and
- WFP residuals with a total alpha activity value exceeding 40 pCi/g of dry solids require additional CDPHE guidance prior to disposal. The residuals generator must contact the CDPHE's Radiation Control Division and the Solid Waste Division for guidance

Colorado drinking water utilities with residuals that have total alpha activity values exceeding 40 pCi/g have disposed of residuals using landfill disposal, sanitary sewer discharge, monofill disposal, and compost amendment with and without approval from CDPHE.

Liquid residuals discharged to sanitary sewers are not regulated for water treatment residuals disposal by CDPHE. Acceptance of water treatment residuals is approved by the sanitary district authority based on impacts to the treatment process from additional flow and solids loading.

Simultaneous Compliance Issue Faced by the Utility

Since the inception of enhanced coagulation at the Allen WFP, analysis of the residuals has shown that the total alpha activity exceeds 40 pCi/g, resulting in the requirement that the City of Englewood must notify CDPHE of disposal plans for the residuals to comply with state regulations. The City can no longer dispose of residuals as has been done in the past because CDPHE no longer allows land application at the golf course. The concentrated residuals are considered technologically enhanced naturally occurring radioactive materials (TENORM). Regulation of TENORM in drinking water residuals is not clearly spelled out in Federal or state regulations.

Steps Taken by the Utility

The City undertook a study to develop a long-term residuals disposal plan. Six disposal alternatives were evaluated using three criteria: compliance with residuals disposal regulations, cost of disposal, and ease of implementation. The six alternatives considered were as follows:

- *Discharge to the sanitary sewer* is not regulated by the state, however the waste water treatment plant (WWTP) has a limit of 30 pCi/g for biosolids. Because liquid residuals samples from the Allen WFP holding pond have an average gross alpha level of 5,880 pCi/L, the allowable discharge rate would be limited to a total flow well below the average daily production rate. This option is therefore not operationally sound;

- *Disposal at an approved landfill* requires loading and trucking residuals to one of two landfills at a distances of 44 miles or 100 miles from the plant site. The landfills are approved for disposal of Resource Conservation and Recovery Act (RCRA) wastes by the State of Colorado and all material disposed is manifested and final disposal location within the landfill is documented. The minimum operating cost of this option is $66,000 per year;

- *Compost/topsoil amendment recycling* requires the City to take responsibility for loading dry residuals onto City trucks to transport to the facility. The compost facility can mix residuals immediately upon delivery to avoid stockpiling of residuals only material. The expected annual operating cost for this option is $19,900;

- *Disposal at a new City monofill* requires the development, operation, and eventual closing of a landfill operation used solely for Allen WFP residuals. In addition, trucking of the residuals to the landfill site would be required. This option requires a capital investment of approximately $1.4 million and annual operating costs of $233,000;

- *On-site mixing with fill material* provides material ready for compost or topsoil application. A portion of residuals is mixed with fill material with low background gross alpha levels. City monitoring for gross alpha will be required to ensure levels below 40 pCi/g. Expected annual operating cost for this option is $68,100; and

- *Disposal at out-of-state approved landfill* assumes transport of residuals by truck or rail cars to the nearest landfill (600 miles away) that accepts TENORM waste similar to the Allen WFP residuals. Material at this facility is manifested and final disposal location in the landfill is documented. The expected annual operational cost is a minimum of $202,500.

In addition to evaluating these six options, the City contracted for a human health risk assessment to be done to determine possible radiation exposure to City and landfill employees from managing the residuals, as well as the public exposure arising from possible future property uses. The risk assessment utilized RESRAD Version 6.21 modeling software to assess the dose to workers and residents from contact with radioactive material in the treatment plant residuals, either directly or indirectly. Included were the possible radiation exposures for a landfill worker, a composting facility worker, and a hypothetical future resident farmer living and farming the area above a closed landfill. The risk assessment indicated that neither the landfill or compost worker would be subject to significant radiation exposure resulting from the residuals handling. In addition, the hypothetical future farmer is unlikely to experience exposures above typical background levels in Colorado. Thus, the risk assessment supported the disposal of residuals in a local landfill and at the compost recycling facility.

As of March 2006, the sludge is being disposed of at a licensed industrial landfill within the state.

The City is assessing coagulation schemes that use less alum and produce less residuals. One such possibility is using a 15 mg/L dose of polyaluminum chloride (PACl) with a small supplemental dose of 8 mg/L of alum. Essential to making this change will be the ability to remove sufficient TOC to meet the Stage 1 D/DBPR.

Since there is currently no state or Federal guidance for disposal of radioactive water treatment residuals, the City has undertaken an effort with other local utilities to assist the State CDPHE in development of guidance for the disposal of TENORM in drinking water residuals.

Results of the Steps Taken

The long-term recommendation to the City is that residuals be transported to the compost/topsoil amendment recycling center. In addition the City is expected to obtain approval for both onsite mixing and in-state landfill disposal. Approval for all three disposal methods has been requested from CDPHE.

The State CDPHE has begun a stakeholder process that will ultimately result in guidance for utilities in disposing of TENORM.

Implementation and Operational Issues Faced by the Utility

The fact that appropriate Federal and state guidance does not yet exist to provide utilities with an understanding of requirements has made managing residuals much more complex. Approval from CDPHE must be obtained as soon as possible as residuals are currently stockpiled on the plant site at near capacity. If residuals handling operations are impacted with respect to volume, the drinking water treatment process may also be impacted with respect to production.

Lessons Learned From this Case Study

- The levels of radioactivity in sludge may be significantly higher than expected based on the background levels in the raw water when the treatment process produces residuals that concentrate contaminants. These residuals can be liquid and/or solid;

- Disposal to the sanitary sewer is likely to be a problem for almost any concentrated contaminant that is regulated in biosolids; and

- No regulatory guidance is available to utilities to assist in developing disposal options for residuals that qualify as TENORM.

State regulatory agency groups that have responsibility for radioactive waste products are generally different from the group responsible for drinking water compliance. This can result in some complex interactions with regulators as the utility may find themselves in the role of initiating internal interactions within state agencies. In Colorado, the Hazardous Materials and Waste Management Division is the licensing group for disposal at hazardous waste disposal facilities or licensed radioactive waste facilities. Discharge permits, if the liquid waste meets water quality standards, are issued by the Water Quality Control Division's Colorado Discharge Permit System. Drinking water is regulated through the Water Quality Control Division Drinking Water Program.

Case Study #7
Granular Activated Carbon Filtration for TOC Removal[1]
Higginsville Water Treatment Plant
Higginsville, Missouri

Introduction

This case study provides an example of how a utility used GAC to address high levels of atrazine in its source water and high TTHM levels in its finished water. Most of the information for this case study came from Leung and Segar (2000). Interested readers are referred to that reference for more information.

The Higginsville, Missouri Water Treatment Plant is a 2 million gallons per day (MGD) treatment plant that draws water from a small surface water impoundment in Missouri. The plant operates 12 hours a day and employs a two stage settling process with conventional filtration. In 1994, the plant experienced a violation of the atrazine maximum contaminant level (MCL). The system eventually switched to GAC caps on their filters to counter the problem.

The source for the Higginsville plant is an impoundment that collects surface runoff from nearby agricultural areas. It has high hardness and TOC. The average source water quality is described in Exhibit B.12.

Exhibit B.12 Average Source Water Quality

Parameter	Average Value
pH	8.1
Alkalinity	89 mg/L as $CaCO_3$
Hardness	129 mg/L as $CaCO_3$
Turbidity	18 NTU
TOC	6 mg/L

The Original Treatment Process at the Higginsville WTP

Exhibit B.13 displays a schematic of the treatment scheme at the Higginsville plant. The plant adds chlorine dioxide to the raw water to control taste and odor problems. Copper sulfate is also added occasionally to control biological blooms that lead to taste and odor problems. The water is then pumped to a first set of coagulation and settling basins. An average of approximately 40 mg/L of alum and 1.7 mg/L of cationic polymer are added. Lime and fluoride are added to a second flash mix prior to the water passing through a second set of coagulation and sedimentation basins. The water is then filtered

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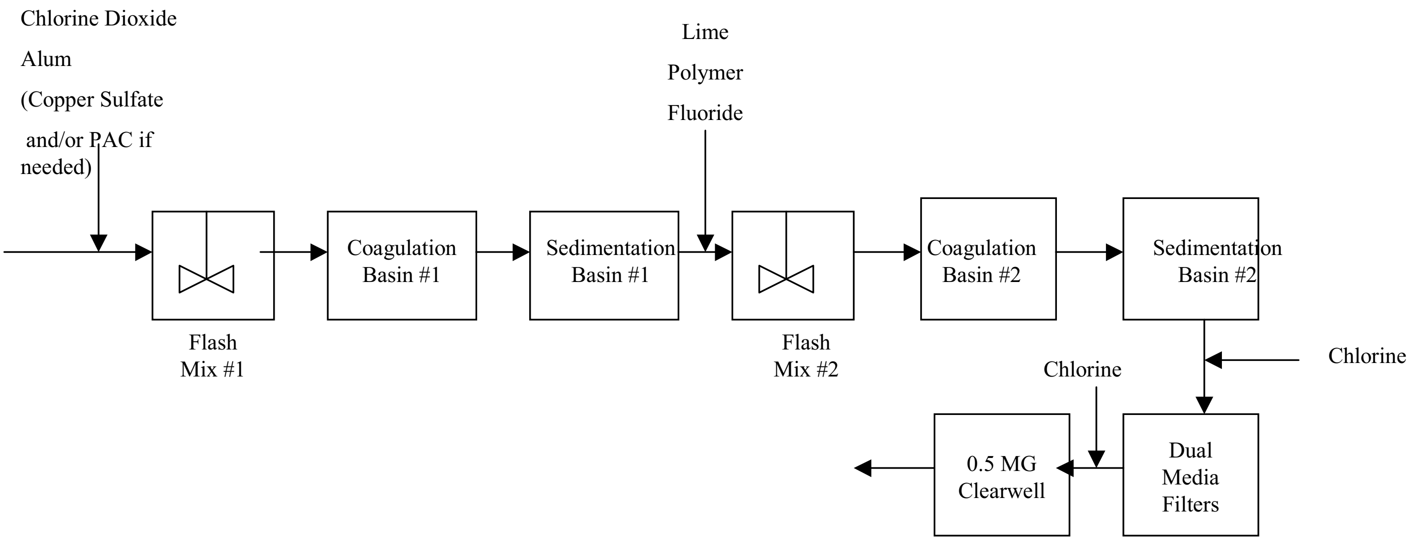
[1] For an example of GAC used as a biological filter after ozonation, see Case Studies 9 and 10.

through dual media filters. Chlorine is added both prior to the filters and to a 0.5 million gallon clearwell after the filters.

When the utility first experienced violations of the atrazine MCL in 1994, it added powdered activated carbon (PAC) in the first flash mixer to combat the problem. Although PAC did lower atrazine concentrations below the MCL, it was limited in removal capabilities because of the short contact time.

Exhibit B.13 Higginsville Water Treatment Plant



Simultaneous Compliance Issue Faced by the Utility

The utility was in violation of the atrazine MCL. In addition, high TOC levels were contributing to total trihalomethane (TTHM) levels which averaged around 80 mg/L, which could cause problems with Stage 1 and Stage 2 DBPR compliance. Although PAC provided a temporary solution to the atrazine problem, it was not desirable as a long term treatment method because of high amounts of sludge. The system also faced periodic taste and odor episodes.

Steps Taken by the Utility

The utility replaced the anthracite in its dual media filters with GAC in an attempt to reduce atrazine concentrations and lower TOC and DBPs. The pre-chlorination residual was also reduced to 0.1 mg/L to prevent degradation of the GAC. Twenty four inches of GAC were placed on top of the sand and gravel base of the filters. The total EBCT was 7.5 minutes.

Results of the Steps Taken

When the GAC caps were first installed, atrazine levels dropped to below detection and DBP precursors as measured by ultraviolet light adsorption at 254 nm (UV_{254}) dropped by 50 percent. After about 3 months of operation the removal rates dropped. Removal rates eventually settled at 30 to 60 percent atrazine removal and 20 percent UV_{254} removal after about 6 months of operation. The atrazine concentrations were always below the MCL of 3 mg/L, averaging between 1 and 2 mg/L. The hydraulic performance of the filter was unaffected by the change to the GAC cap. Turbidity values leaving the filters were comparable to values produced previously with the anthracite filters.

Implementation and Operational Issues Faced by the Utility

Adsorption of atrazine and other organics onto the GAC gradually decreased removal rates over time. A build up of inorganic precipitates, largely calcium, was seen on the GAC, which also contributed to decreased removal rates. The removal rates can be restored by regenerating or replacing the GAC, though this can be expensive.

It is possible that initial removal was due to adsorption and biological activity was later established. If this were the case, subsequent removal resulted from a combination of adsorption and biological degradation. If biological activity is suspected, care should be taken not to change the operational characteristics (e.g., fluidized bed heights, backflow rates) since changes in these operational parameters might impact removal performance.

There was a trade-off between removal of atrazine and removal of UV_{254}. Lower pH favored UV_{254} removal at the expense of atrazine removal, while high pH had the opposite effects.

The system still experiences occasional taste and odor episodes. This is most likely caused by taste and odor causing compounds passing through the filters because GAC contact time and design are not optimal for taste and odor control. These episodes have been dealt with by adding PAC prior to the filters.

Lessons Learned From this Case Study

- GAC caps can be used effectively to reduce pesticide and TOC concentrations;
- Adsorption of organic compounds by GAC is complicated and depends on the concentrations of other adsorbing compounds present in the source water. Bench scale tests should be done on the specific source water to determine if GAC itself, as well as different brands of GAC, will be effective with that water; and
- The pH of the water can impact GAC removal rates for different organic compounds.

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Case Study # 8
Nanofiltration Membrane Technology for TOC Removal
PBCWUD Water Treatment Plant #9
West Palm Beach, Florida

The Palm Beach County Water Utilities Department (PBCWUD) utilizes groundwater supplies that are treated at Water Treatment Plant # 9 (WTP #9) acquired by the County in 1983. The original plant, constructed in 1971 by private developers, utilized lime softening, rapid sand filtration, short-term free chlorination for biological growth control in the filters and chloramination for secondary disinfection. The facility had a maximum day flow capacity of 13.45 MGD, and was comprised of three treatment trains with capacities of 1 MGD, 3 MGD, and 10 MGD.

Initially, the plant provided water service to the local area, but it was later incorporated into the regional water distribution system to provide potable water for the southern portion of the PBCWUD Service Area. Recognizing the growing demands for water in the area and the implementation of new drinking water standards, PBCWUD administered a construction contract for a new 27 MGD nanofiltration plant that was awarded in 1999. Nanofiltration removes hardness, color, and TOC and its related chlorinated DBPs which are commonly found in South Florida ground water. The plant started operational testing in November 2001.

This case study provides an example of several simultaneous compliance issues that can be associated with nanofiltration membrane technology. These issues were identified during initial start-up operations and have been resolved successfully. The issues include:

- DBP Rules - ability to remove DBP precursors;
- LCR - ability to provide a non-corrosive water in the PBCWUD distribution system; and
- Secondary Drinking Water Standards - ability to provide an aesthetically pleasing water to PBCWUD customers.

Introduction

The mission of PBCWUD is to provide the highest quality drinking water service in a fiscally and environmentally sound manner. In the last decade, with the enforcement of the Secondary Drinking Water Standards and the Stage 1 D/DBPR in the State of Florida, PBCWUD's capital improvement strategy for new water treatment plants has been focused on nanofiltration membrane technology. Membrane water treatment technology is cost competitive with traditional conventional treatment methods while producing higher quality potable water; consequently, becoming the dominant water treatment technology in South Florida.

In May of 2003, PBCWUD completed Phase I construction of a new, and one of the largest in the world, nanofiltration membrane treatment plant (WTP #9) with a maximum capacity of 27 million gallons per day (MGD) finished water, including 23 MGD of membrane permeate and 4 MGD of raw blend water. As stated previously, the primary reason for the membrane softening is for removal of hardness, color, TOC, and its related chlorinated DBPs.

The raw water supply for WTP #9 is water from the local surficial Biscayne Aquifer. The surficial aquifer system provides the water source for most public water supply wellfields in southeastern Florida. The aquifer system is generally unconfined and extends from land surface to a depth of approximately 330 feet below land surface (bls). The ground water is generally colored due to organics, hard and alkaline with varying amounts of dissolved iron and hydrogen sulfide. Typical ranges of water quality found in the Biscayne Aquifer are shown in Exhibit B.14.

Exhibit B.14 Typical ranges of raw water quality in the Biscayne Aquifer

Water Quality Parameter	Units	Range of Values
pH	Standard Units	7.0-7.5
Alkalinity	Mg/L as CaCO3	200-240
Chloride	Mg/L	<250
Total Dissolved Solids	Mg/L	250-600
Hardness	Mg/L as CaCO3	225-275
Sulfate	Mg/L	15-25
Total Organic Carbon	Mg/L	10-12
Color	Color Units	360-400

The New Treatment Process at Water Treatment Plant #9

The treatment train for WTP #9 is shown in Exhibit B.15. The raw water supplied to WTP #9 is taken from the shallow surficial aquifer through a series of 24 wells. Pretreatment includes a sand strainer which removes bulk sand from the raw water stream, acid injection to control pH to 5.0-5.9, and 5-micron cartridge filters to remove particulates greater than 5 microns. Six membrane feed pumps located after the micron filters boost the feed water pressure to 125-132 psi. The nanofiltration membrane building includes eight membrane treatment trains where each one has two stages with 47 and 22 pressure vessels, respectively. The degasifier/odor control system functions to remove hydrogen sulfide and carbon dioxide from the permeate water (product water from the membranes) and to prevent the emission of odors into the atmosphere. A sodium hypochlorite system supplies dilute liquid chlorine for disinfection. Six high service pumps supply water to the distribution system. Post-storage chemical injection points for ammonia, chlorine, and caustic soda are included in the system to allow final disinfection and/or pH adjustment before the finished water enters the distribution system. The water entering the distribution system is monitored for chlorine residual, pH, pressure, and flow. The impurities removed by the membrane softening trains are consolidated into a concentrate stream and discharged through three-concentrate booster pumps into one deep injection well.

Treatment Steps Taken by Palm Beach County

- Pretreatment of sand strainer, acid injection, cartridge filtering
- Eight nanofiltration membrane treatment trains
- Degasification and odor control
- Dilute chlorine disinfection
- Post-storage final disinfection and/or pH adjustment and control
- Distribution system monitoring

Simultaneous Compliance Issues Faced by the Utility

Nanofiltration membranes remove organic compounds in a molecular weight range of 200 to 20,000 Daltons and reject selected salts (typically divalent). Nanofiltration economically softens water without the use of salt-regenerated systems and provides unique organic removal capabilities. While effective in removing organic constituents or DBP precursors, the nanofiltration membrane rejects selected salts, producing treated water with low total dissolved solids (TDS). Low TDS water has poor buffering capacity and can lead to low pH water, which is corrosive to metal pipes. Generally, an alkalinity below 25 mg/L as $CaCO_3$ (0.5 meq/l) can be problematic for corrosion of piping (AwwaRF and DVGW-Technologiezentrum Wasser 1996). This chemically unstable water can result in compliance issues with the Secondary Drinking Water Standards and the LCR.

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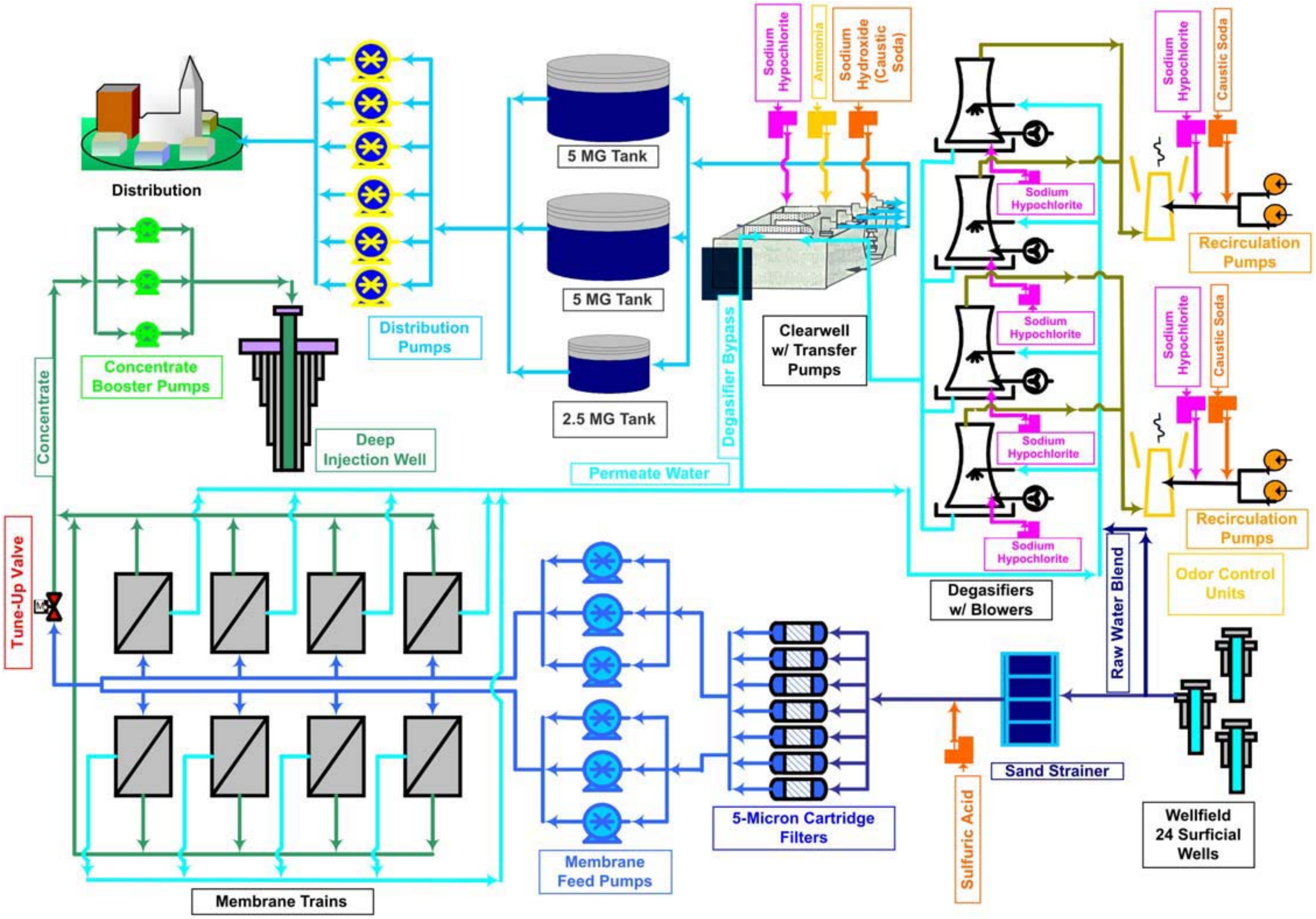
Exhibit B.15 Water Treatment Plant #9 Treatment Train



Steps Taken by the Utility

Steps taken by the utility to overcome the potential simultaneous compliance issues discussed above occur primarily in the post-treatment process. The post-treatment process is mainly taking place in the clearwell complex area as shown in Exhibit B.15. The clearwell complex consists four major processes: 1) de-gasification process for de-gasification of hydrogen sulfide and carbon dioxide from the permeate solution, 2) odor control process to remove hydrogen sulfide from the air, 3) clearwell disinfection process to create free and combined chlorine, and 4) transfer pump process to discharge the post-treated water to the storage tanks.

Prior to the de-gasification process, approximately 4 MGD of raw water is introduced into the treatment train to blend with the 23 MGD of treated water. Blending of this raw water introduces some of the divalent salts back into the water that had been previously rejected by the membrane. This provides a more chemically-stable finished water.

Permeate water from the nanofiltration trains contains excessive amounts of carbon dioxide and hydrogen sulfide; therefore, 4 identical de-gasifier towers with air blowers in the clearwell complex function to remove carbon dioxide (CO_2) and hydrogen sulfide (H_2S) from the permeate water with the air stripping process. Sodium hypochlorite is injected into the permeate water before entering into the de-gasifiers for disinfection. The towers are of the forced draft, randomly packed bed, counter flow type.

The de-gasifiers are designed for maximum influent pH of 6 std. units; influent H_2S with concentration of 1.3 mg/L and removal efficiency of 92 percent; and influent CO_2 with concentration of 77 mg/L and with removal efficiency of 93.5 percent.

The stripped permeate is treated with a chlorine solution and ammonia for secondary disinfection and caustic soda for pH adjustment.

Results of the Steps Taken

The resulting finished water quality is listed in Exhibit B.16.

Exhibit B.16 Typical ranges of distribution system water quality

Water Quality Parameter	Units	Range of Values
Total Trihalomethanes	ppb	ND-55.3
Haloacetic Acids	ppb	ND-51.4
pH	Standard Units	8.5-9.0
Alkalinity	mg/L as CaCO3	30-50
Chloride	mg/L	17.2-110
Total Dissolved Solids	mg/L	90-300
Hardness	mg/L as CaCO3	40-60
Sulfate	mg/L	6.0-19.5
Total Organic Carbon	mg/L	<0.5
Color	Color Units	1-7
Lead	ppb, 90th percentile	3
Copper	ppm, 90th percentile	0.134

As shown in Exhibit B.16, all Secondary Drinking Water Standards, DBP Rule MCLs, and LCR Action Levels are met.

Implementation and Operational Issues Faced by the Utility

The utility experienced two serious problems in bringing the nanofiltration membrane treatment plant online. The most serious problem involved numerous leaks in the acid feed system. As a result of the leaks, the acid system had to be completely rebuilt during the first year of operation.

The other problem involved the micron cartridge filter housings and the string wound filter. The filter housings use a single open end cartridge with a stainless steel spring on the other end to keep tension on the cartridge, holding it in place. In this case, the filters sagged in the middle causing them to pull out of the socket. With the filter out of place, sand and debris accumulated on the membranes. This problem was eliminated by modifying the cartridge housings with a center bracket to support the filters. With these two modifications, the treatment plant has worked very well and continues to produce very high quality water.

Lessons Learned From This Case Study

- Nanofiltration economically softens water without the use of salt-regenerated systems and provides unique organic removal capabilities thereby removing disinfection byproduct precursors;

- Blending a portion of the raw water with treated water and the de-gasification process significantly enhances the aesthetic qualities of the finished water and results in a more chemically stable water. This enables PBCWUD to provide their customers with water that complies with both the LCR and the Secondary Drinking Water Standards; and

- The nanofiltration membranes should be evaluated by monitoring conductivity in the permeate from the membrane train and from each membrane pressure vessel as necessary to isolate a problem. Monitoring TOC, particle count or HPC are not necessary.

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Case Study #9
Modifying Chloramination Practices to Address Nitrification Issues
Ann Arbor Utilities[2]
Ann Arbor, Michigan

This case study demonstrates how a utility modified chloramination practices to address nitrification problems in the distribution system to be in compliance with the Stage 1 DBPR and the TCR.

Introduction

The City of Ann Arbor operates a two-stage lime softening plant (50 million gallons per day (MGD) design flow) that treats a blend of surface water and ground water. It serves approximately 115,000 people. The influent to the plant consists of a blend of Huron River water (approximately 85 percent) and well water (approximately 15 percent). Typical water quality parameters for raw river water and well water, prior to any treatment modifications, are presented in Exhibit B.17. The water entering the plant has high alkalinity (average alkalinity of 314 mg/L as $CaCO_3$), with high TOC levels (average 6 mg/L).

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[2] This system is also used in Case Study #10 Ozonation.

Exhibit B.17 Summary of Relevant Water Quality Parameters at Ann Arbor Before Treatment Modifications

Water Quality Parameters	Location[1]			
	River	**Well**	**Blended Influent**	**Effluent**
TOC (mg/L)				
Minimum	5.5	1.0	5.1	2.1
Average	6.9	2.2	6.0	3.0
Maximum	8.7	5.9	8.1	3.5 (3.7)[2]
pH				
Minimum	7.9			9.3 (9.1)[2]
Average	8.1			9.4
Maximum	8.2			9.7
Alkalinity (mg/L as $CaCO_3$)				
Minimum	205	301	218	28
Average	215	314	234	39
Maximum	228	335	250	48
Total Coliforms (#/100 ml)				
Minimum	62	0		
Average	781	0		
Maximum	2,890	0		
***Cryptosporidium* (# oocysts/100 gallons)**				
Minimum				
Average	ND			ND
Maximum	114			ND
	1,739			ND

Notes:

1. Data collected between July 1994 and June 1995; based on monthly (average) data.
2. Minimum or maximum values (in parentheses) represent minimum or maximum of all measurements, not limited to monthly average data.
3. ND = Non Detectable

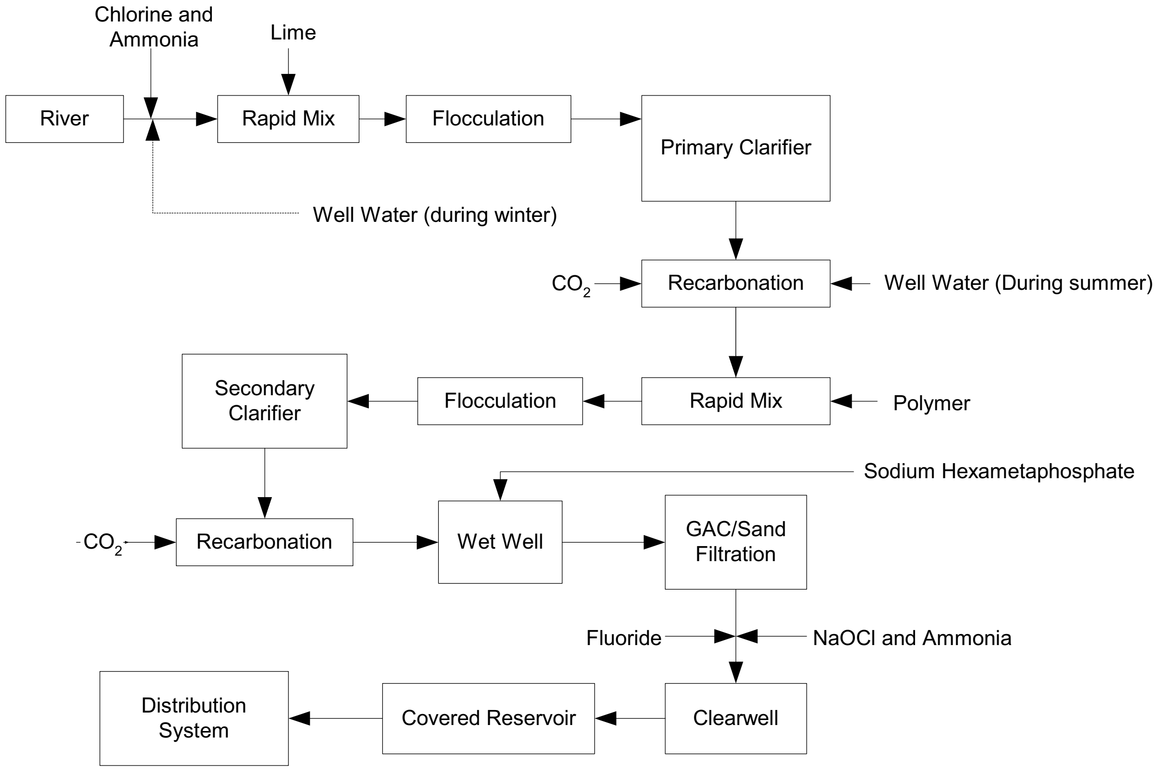
The Treatment Process at the Ann Arbor WTP

The treatment plant is a 50 MGD two-stage lime softening plant that uses chloramines for primary disinfection. The average operating flow is 20 MGD. Exhibit B.18 shows a schematic of the treatment plant. Raw river water is disinfected with chlorine, then chlorine is added again with ammonia after filtration to form chloramines. The free chlorine contact time is minimal. The water is softened with lime (average dose = 187 mg/L as $CaCO_3$), at a pH slightly above 11. From April through November well water is blended with softened water from the first stage clarifier effluent and recarbonated (i.e., addition of CO_2) to bring the pH down to around 10. It then enters the second-stage clarifier. A cationic polymer is added at this point (average dose 0.62 mg/L) to enhance settling. The water is then recarbonated (i.e., CO_2 is added) down to a pH slightly greater than 9, and sodium hexametaphosphate is added to facilitate corrosion control. The water is then filtered (granular activated carbon (GAC)/sand dual-media filters). After filtration, sodium hypochlorite and ammonia are added to form chloramines and the finished water is distributed at an average pH of 9.4.

From December through March the chemical application points are similar to those during the summer months. However, the well water is blended with the river water prior to the first stage of the lime softening process to raise the water temperature and improve sludge dewatering.

The chloramines dose ranged from 4.1-6.2 mg/L and *Giardia* log inactivation by chloramination ranged from 0.5 to1.0 logs.

Exhibit B.18 Ann Arbor Water Treatment Plant



Simultaneous Compliance Issue Faced by the Utility

The system switched to chloramines to reduce TTHM formation and to be in compliance with the Stage 1 Disinfectants/Disinfection Byproducts Rule (D/DBPR). However, the use of chloramines can result in the presence of ammonia in the distribution system if the proper chlorine to ammonia (as nitrogen) ratio is not maintained. This increases the potential for biological nitrification. Nitrification can result in a loss of combined chlorine residual, and result in sharp increases in HPC bacteria. This increases the chances of a TCR violation.

Steps Taken by the Utility

To cope with the nitrification problem, Ann Arbor expanded its monitoring program and made several operational and facility adjustments to improve ammonia feed rate control. The chlorine to ammonia (as nitrogen) ratio was maintained at 4.75:1, with a target level for free ammonia entering the distribution system of 0.15 mg/L. Warning and action levels for nitrite in the system were set at 0.025 and 0.050 mg/L, respectively.

As soon as the utility became aware of its nitrification problem, it attempted to control it by controlling the concentration of free ammonia reaching the filters. No changes were made to the existing treatment configuration. However, the system made several operational changes. Ammonia dosage at the headworks was reduced so that less than 0.15 mg/L of free ammonia remained in the water when it entered the filters. Along with this, distribution lines were flushed at low velocity until an average combined chlorine residual of approximately 3 mg/L was achieved. The Stage 1 DBPR specifies a running annual average maximum residual disinfectant level (MRDL) for chlorine of 4.0 mg/L (as Cl_2).

During the summer months (i.e., June to September), the system switched back to chlorination. This was achieved by simply shutting down ammonia addition after filtration and adjusting the chlorine feed rate. This would ensure that nutrient levels (i.e., ammonia) in the distribution system were low during the warmer months, when the temperature was most conducive to the rapid growth of nitrifying organisms. This would decrease biological activity in the distribution system.

Results of the Steps Taken

As a result of these steps, nitrite concentrations in the distribution system were below detection level. Also, HPC levels dropped significantly in five of the six locations where nitrification had previously been found. The system did see an increase in TTHM formation during the summer months. However, careful monitoring, dosing, and complementary hydrant flushing (see next paragraph for details) resulted in compliance with the Stage 1 DBPR. The average and maximum TTHM in the finished water were 24 and 39 μg/L, respectively (based on the monthly TTHM data collected between July 1994 and June 1995).

Implementation and Operational Issues Faced by the Utility

Although switching to free chlorine during the summer was effective for controlling nitrification, it appeared to result in higher levels of heterotrophic and coliform bacteria than when the water was chloraminated. At the same time, increasing the chlorine dose during the summer months increased TTHM concentrations. As a result, the system decided to continue disinfecting with chloramines and pursue a more aggressive hydrant flushing program to control bacterial re-growth in the distribution system.

Analysis revealed that one of the prime causes of nitrification could have been the switch to a GAC/sand dual-media filter from a pure sand filter. The ammonia added before the water reached the filters could have provided a nutrient source sufficient for nitrifying bacteria to attach, establish, and proliferate within the GAC media. Such a condition could have allowed the nitrifying organisms to pass through the filter and seed the distribution system if they survived the chloramine disinfection.

Lessons Learned From this Case Study

- Controlling nitrification in the distribution can be a challenge for utilities switching to chloramines;
- Carrying a chloramine residual through the treatment plant might increase distribution system problems with biological nitrification;
- The most common strategies for controlling nitrification are listed below.
  - Improving ammonia feed rate control to limit the free ammonia levels entering the distribution system;
  - Implementing a comprehensive distribution system flushing and monitoring program; and
  - Having an alternative disinfection strategy for the warmer months of the year.
- Systems adding ammonia prior to a GAC filter may be more likely to face nitrification in the distribution system.

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Case Study #10
Ozonation
Ann Arbor Utilities[3]
Ann Arbor, Michigan

This case study demonstrates how a utility switched to ozonation to meet the Interim Enhanced Surface Water Treatment Rule (IESWTR) and the Stage 1 and 2 DBPR regulations, and simultaneously controlled microbial regrowth potential in the distribution system to be in compliance with the TCR.

Introduction

The City of Ann Arbor serves approximately 115,000 people, and operates a two-stage lime softening plant (50 MGD design flow) that treats a blend of surface water and ground water. In 1990, for the reasons outlined below, the Ann Arbor plant decided to switch from chloramines to ozonation for primary disinfection.

- Ozonation would meet IESWTR CT requirements for viruses at low temperatures;
- In addition to complying with the IESWTR, ozonation was expected to allow the plant to comply with Stage 1 and 2 DBPRs; and
- Ozonation was also expected to improve taste and odor.

The influent to the plant consists of a blend of Huron River water (approximately 85 percent) and well water (approximately 15 percent). Typical water quality parameters for raw river water and well water, prior to any treatment modifications, are presented below in Exhibit B.19. The water entering the plant has high alkalinity (average influent alkalinity of 314 mg/L as $CaCO_3$), with high TOC levels (average 6 mg/L).

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[3] This system is also used in Case Study #9 Modifying Chloramination Practices to Address Nitrification Issues.

Exhibit B.19 Summary of Relevant Water Quality Parameters at Ann Arbor Before Treatment Modifications

Water Quality Parameters	Location[1]			
	River	**Well**	**Blended Influent**	**Effluent**
TOC (mg/L)				
Minimum	5.5	1.0	5.1	2.1
Average	6.9	2.2	6.0	3.0
Maximum	8.7	5.9	8.1	3.5 (3.7)[2]
pH				
Minimum	7.9			9.3 (9.1)[2]
Average	8.1			9.4
Maximum	8.2			9.7
Alkalinity (mg/L as $CaCO_3$)				
Minimum	205	301	218	28
Average	215	314	234	39
Maximum	228	335	250	48
Total Coliforms (#/100 ml)				
Minimum	62	0		
Average	781	0		
Maximum	2,890	0		
Cryptosporidium (# oocysts/ 100 gallons)				
Minimum	ND			ND
Average	114			ND
Maximum	1,739			ND
TTHM (μg/L)				
Minimum				14
Average				24
Maximum				39
HAA5[4] (μg/L)				
Minimum				4.2
Average				16
Maximum				21

Notes:

Data collected between July 1994 and June 1995; based on monthly (average) data.

Minimum or maximum values (in parentheses) represent minimum or maximum of all measurements, not limited to monthly average data.

ND = Non Detectable

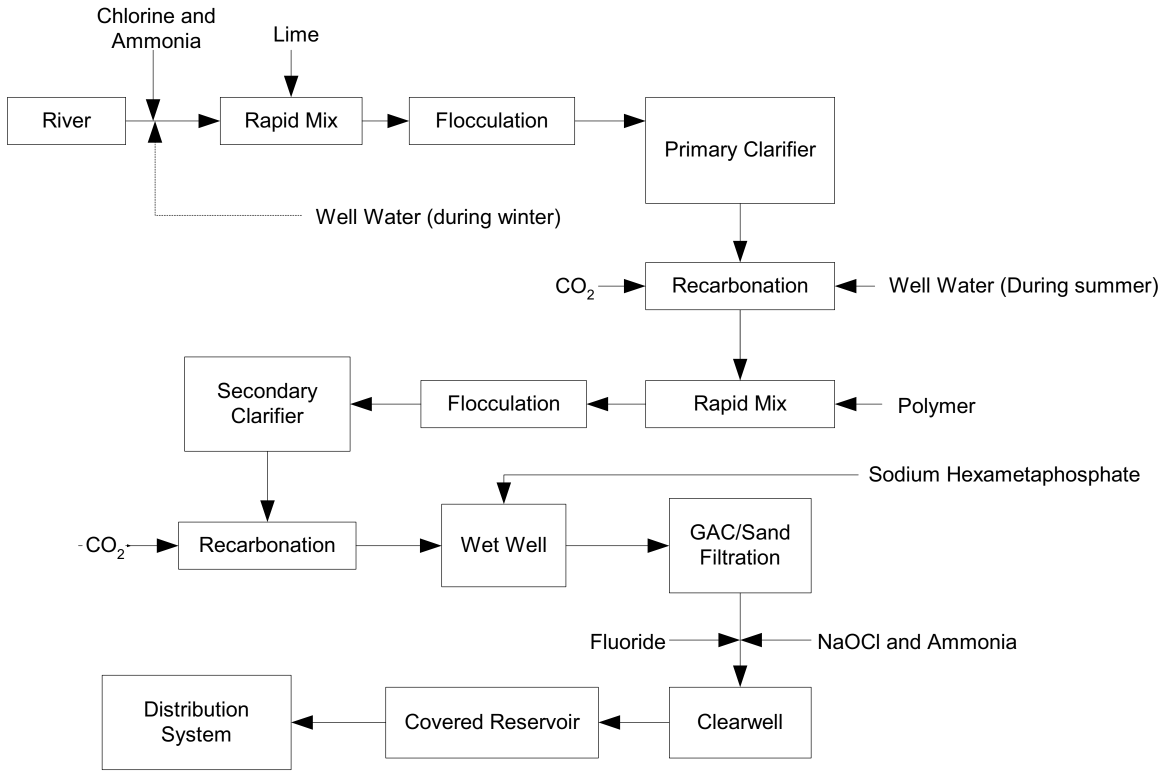
Data collected quarterly between October 1995 and May 1996.

The Original Treatment Process at the Ann Arbor WTP

The original treatment plant was a 50 MGD two-stage lime softening plant that used chloramines for primary and secondary disinfection. The average operating flow was 20 MGD. Exhibit B.20 shows a schematic of the treatment plant, prior to the modifications. Raw river water was disinfected with chlorine, followed by ammonia addition to form chloramines. The free chlorine contact time was minimal. The water was softened with lime (average dose = 187 mg/L as $CaCO_3$), at a pH slightly above 11. From April through November, well water was blended with softened water from the first stage clarifier effluent and recarbonated (i.e., addition of CO_2) to bring the pH down to around 10. It then entered the second-stage clarifier. A cationic polymer was added at this point (average dose 0.62 mg/L) to enhance settling. The water was then recarbonated down to a pH slightly greater than 9 and sodium hexametaphosphate added, to facilitate corrosion control. It was then filtered (GAC/sand dual media filters). After filtration, sodium hypochlorite and ammonia were added to boost the level of chloramines. The finished water was distributed at an average pH of 9.4.

From December through March the chemical application points were similar to those during the summer months. However, the well water was blended with the river water prior to the first stage of the lime softening process to raise the water temperature and improve sludge dewatering.

Exhibit B.20 Ann Arbor Water Treatment Plant Before Treatment Modifications



Simultaneous Compliance Issue Faced by the Utility

Application of ozone would lower the formation of TTHM and HAA5s and enhance the ability to meet minimum virus and *Giardia* inactivation levels (to be in compliance with the IESWTR). However, ozonation could lead to an increase in the AOC levels in the finished water, resulting in potential microbial regrowth in the distribution system and non-compliance with the TCR.

Steps Taken by the Utility

The utility switched to ozonation, followed by biofiltration, in order to address the simultaneous compliance issue. They no longer pre-chlorinate or pre-chloraminate.

Before switching to ozone, the operators of Ann Arbor’s system contacted known ozone facilities and talked with their engineers and operators to learn what features, in retrospect, they wish they had installed when they installed the ozone. Based on these discussions, some features missing from previous plant designs were incorporated into the Ann Arbor system’s design. One example of such as a feature is the addition of waterproof hatches for direct access to the contact chambers. This eliminated the need for roof entry, which is an important consideration for system operators.

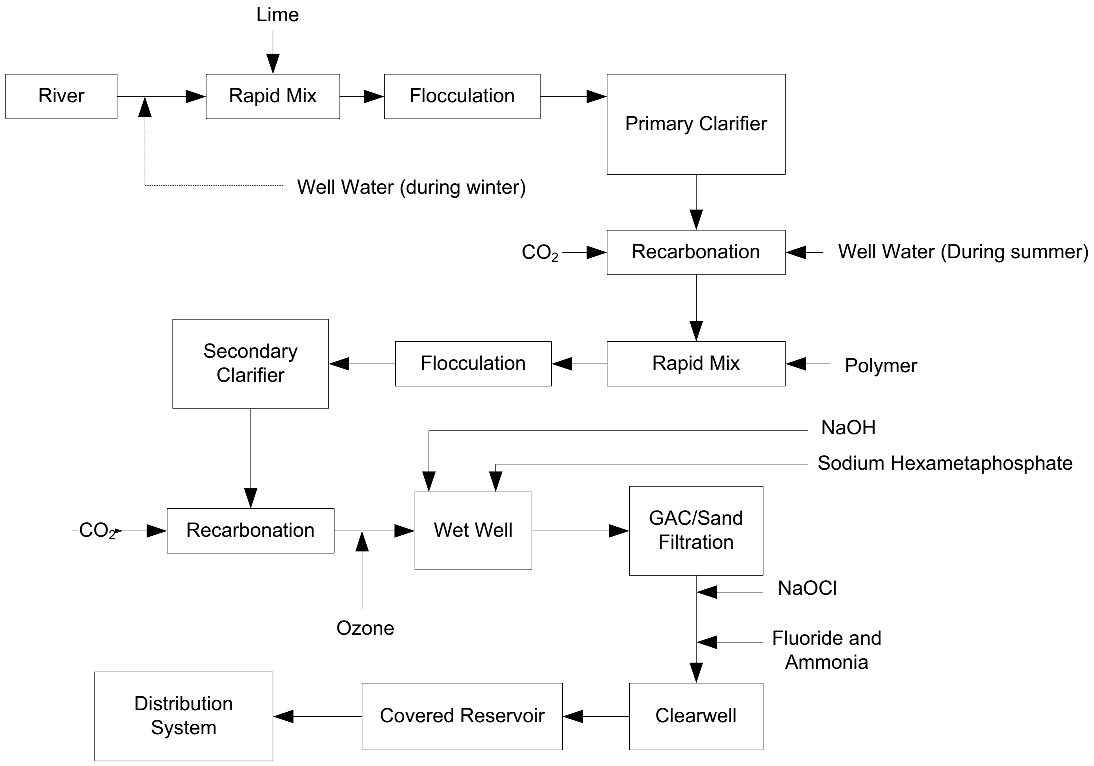
Overall process – Exhibit B.21 shows a schematic of the treatment plant after the modifications. Changes made to the original treatment train are outlined below.

- Ozonation is now the primary disinfection step. The pre-chlorination step was eliminated;
- The first point of disinfectant addition (i.e., ozonation) is after the secondary clarifier, and recarbonation. The ozonation pH is 8.0;
- After ozonation, sodium hydroxide is added to raise the pH of the water to 9.4 prior to adding sodium hexametaphosphate as a corrosion inhibitor; and
- The original dual media (GAC/sand) filters are now operated as biofilters. To help inactivate HPC bacteria shed from the filters, filter effluent is disinfected with an average chloramine dose of 3.5 mg/L, and held for approximately 3 hours in the covered reservoir.

Ozonation Details

There are 8 ozone contact cells with an overall contact time of 16.8 minutes. The system is operated at a 6 to 10 percent gas concentration. An off-gas recycle system applies ozone to the first cell, which reduces demand in subsequent cells but does not produce an ozone residual. The goal is to achieve a residual of 0.1 mg/L or greater in the first cell, and to maintain sufficient residuals in subsequent cells, to meet the target CT.

Exhibit B.21 Ann Arbor Water Treatment Plant After Treatment Modifications



Biofiltration Operations

The filter consists of 18 inches of GAC and 6 inches of sand. The filtration rate varies from 0.76 to 3.0 gpm/ft^2. The empty bed contact time (EBCT) of the GAC is 3.7 minutes at design flow and 7.4 minutes at typical flow. Filter backwash frequency is governed by: (a) effluent turbidity exceeding 0.2 nephelometric turbidity units (NTU), (b) number of hours in service (usually 80 hours is the cut-off point), and (c) acceptable headloss limits (which is usually not a controlling criterion). The backwash is performed using finished chloraminated water.

Results of the Steps Taken

- DBP reductions - Exhibit B.22 shows the TTHM and HAA5 concentrations before and after the modifications at the Ann Arbor plant. Clearly, ozonation resulted in a significant drop in TTHM and HAA5 concentrations, resulting in no compliance problems with the Stage 1 and Stage 2 DBPRs;

- Bromate formation - Ozonation can oxidize bromide to bromate, which is regulated by the Stage 1 DBPR at an MCL of 10 μg/L. Influent bromide concentrations at the ozonation plant ranged from 27 to 80 μg/L, with an average of 67 μg/L. The well contributes more to the bromide levels than the river water. The average bromide concentration in the ground water is 100 μg/L, and the Huron River water has an average bromide concentration of 59 μg/L. The bromate levels in the finished water ranged from 2 to 8 μg/L, with an average of 3 μg/L. At its current level of bromate formation, Ann Arbor meets the bromate MCL; and

- TOC removal - The average influent TOC to the plant after the modifications was 5.5 mg/L (with a range of 4.5-7.0 mg/L). The average effluent TOC was 2.7 mg/L (with a range of 2.1-3.4 mg/L). Therefore, TOC removal ranged from 40 to 59 percent with an average of 51 percent, which is quite similar to the TOC removals achieved before implementing ozonation. The Stage 1 D/DBPR TOC removal requirements for softening plants with an influent TOC >4.0-8.0 or >8.0 mg/L are 25 and 30 percent, respectively (USEPA 1998a). The Ann Arbor plant exceeds these requirements. Higher TOC removal has the advantage of lowering the ozone dose requirements because the ozone applied is not used up by reactions with TOC.

Exhibit B.22 DBP Formation Before and After Ozonation at Ann Arbor

DBPs	Before Modification[1]	After Modifications[2]
TTHM (μg/L)		
Minimum	14	1.4
Average	24	7.2
Maximum	39	13
HAA5 (μg/L)		
Minimum	4.2	1.5
Average	16	5.0
Maximum	21	15
Bromate (μg/L)		
Minimum		2
Average		3 or 4[3]
Maximum		8

Notes:
1. Monthly TTHM data collected between July 1994 and June 1995; other DBP data collected quarterly between October 1995 and May 1996.
2. Data collected in calendar year 1997; based on monthly or quarterly data.
3. Depending on whether the non-detects were set to zero or half the minimum detection level.

Implementation and Operational Issues Faced by the Utility

- Operator training and start-up - It took about 2 to 3 months for the operational staff to be at ease with the new technology, and about 3 to 5 months for the plant to operate optimally and smoothly. The change in treatment also changed the operational needs of the plant; additional mechanics and instrumentation technicians were needed. Additional resources had to be allocated to treatment operation and maintenance;

- Sludge accumulation over diffusers - This caused fluctuating ozone residuals, resulting in difficulty obtaining the required CT. The plant has been testing various chemicals to improve secondary settling to reduce the impact of the sludge on the ozone system;

- Liquid Oxygen (LOX) vaporizers did not defrost well in winters, causing the system to shut down due to low gas flow; and

- Optimizing biofiltration during winters - Extremely large seasonal fluctuations in temperature have strongly governed treatment strategy at the Ann Arbor plant. Average monthly river water temperature in 1997 ranged from 7.9 to 22°C, with an average of 14°C. The lowest temperature in winter during the sampling period was 3°C. Well water temperatures are fairly constant at 14°C. After ozonation and biofiltration, AOC content ranged from 40 to 210 μg C/L (average = 129 μg C/L). During the summer, approximately 40 percent of AOC produced by ozonation was removed during biofiltration, whereas in winter there was practically no removal. This suggests poor biological activity on the filters in winter months. Ann Arbor raises the temperature of the influent water in winter by mixing in a larger proportion of ground water (24-29 percent versus 10-20 percent in the summer). It also introduces well water at the head of the plant in winter to increase the water temperature so that treatment processes like biofiltration are more effective.

Lessons Learned From this Case Study

- Ozonation requires a high degree of operational expertise. The key to running a successful ozonation treatment unit depends greatly on the operator being comfortable with the new instrumentation and controls;

- Ozonation may not be suitable for influent waters with high bromide concentrations; and

- Ozonation increases the AOC concentration in finished water. As a result, biofiltration is required downstream of ozonation to ensure AOC removal and reduce the opportunity for microbial regrowth in the distribution system. Failure to do so may result in TCR violations. Biofiltration needs careful monitoring and optimization, especially during winter when microbial activity is greatly reduced. One operational strategy is to increase the proportion of ground water in the influent surface/ground water blend during winter to ensure that treated water has a higher temperature.

Case Study #11
Ozonation and Biological Filtration
Sweeney Water Treatment Plant
Wilmington, North Carolina

This case study provides an example of a water system that upgraded its treatment plant by expanding its capacity from 15 MGD to 25 MGD and installing ozonation and biological filtration to improve compliance with IESWTR and LT2ESWTR regulations and to increase aesthetics and customer confidence.

The majority of the information for this case study was found in Najm et al., (2005). For more information on the Sweeney Water Treatment Plant, please refer to Kennedy et al. (2004).

Introduction

Sweeney Water Treatment Plant (SWTP) is owned and operated by the City of Wilmington, NC. SWTP uses the Cape Fear River water as its source water, which has high organic content, high color, and low turbidity. The source water also contains iron and manganese that can cause aesthetic issues in the finished water. A summary of the source water quality as received at the SWTP is provided in Exhibit B.23.

Exhibit B.23 Cape Fear River Water Quality (as received at the SWTP)

Water Quality Parameter (Unit)	Average	Minimum	Maximum
TOC (mg/L)	5.6	4.8	8.3
DOC (mg/L)	5.4	4.6	7.6
Filtered UV-254 Abs. (cm^{-1})	0.218	0.123	0.337
Specific ultraviolet absorbance (SUVA) (L/(mg-m))	4.0	2.7	4.4
Color (PCU)	46	25	76
Alkalinity (mg/L as $CaCO_3$)	25	16	30
pH	6.5	5.8	6.8
Turbidity (NTU)	16	3.5	73
Temperature (^{o}C)	20	11	28

Source: Adapted from Najm, et al., 2005
Note: Data collected between Oct. 2001 - July 2002

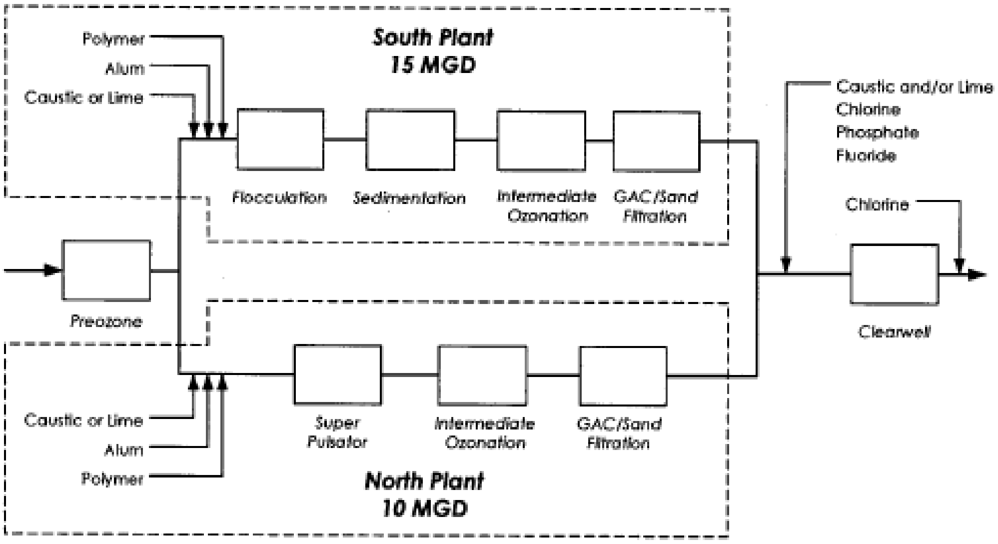
The treatment train for the SWTP is shown schematically in Exhibit B.24 below. The capacity of the SWTP is 25 MGD, and consists of the following two treatment trains:

South Plant (15 MGD)
- Coagulation
- Flocculation
- Sedimentation train
- Intermediate ozonation
- Dual-media GAC/sand filtration

North Plant (10 MGD)
- Coagulation
- High rate clarification (SuperPulsator)
- Intermediate ozonation
- Dual-media GAC/sand filtration

Source water first undergoes pre-ozonation and is then split between the North and South Plants, where the alkalinity is raised by adding caustic and/or lime. During the rapid mix step of each treatment train, alum and cationic polymer are added. Primary disinfection requirements of 0.5-log *Giardia* removal and 2-log virus inactivation are satisfied via the intermediate ozonation step. After undergoing filtration, the treated waters from the South Plant and North Plant are joined and caustic and/or lime, chlorine, phosphate, and fluoride are added to the combined filter effluent (CFE) before the water enters the clearwell. Finally, the effluent of the SWTP's clearwell receives additional chlorination prior to entering the distribution system.

Exhibit B.24 Schematic of SWTP



Source: Najm, et al., 2005

Simultaneous Compliance Issue Faced by the Utility

The City of Wilmington upgraded its facility for the following reasons:

- To better accommodate future population growth;
- To comply with LT2ESWTR regulations by providing *Cryptosporidium* inactivation; and
- To improve aesthetics and customer confidence.

Application of ozone also lowers the formation of TTHM and HAA5. However, ozonation could lead to an increase in the AOC levels in the finished water, resulting in potential microbial regrowth in the distribution system and non-compliance with the TCR. Biofiltration was used to remove AOC before the water entered the distribution system.

Steps Taken by the Utility

Changes made to the original treatment train of the SWTP are outlined below.

- The North Plant (10 MGD facility) was constructed to be operated simultaneously with the existing South Plant (15 MGD);
- An ozone generation and dissolution facility was constructed;
- New pretreatment facilities were built for coagulation;
- 12 sand/anthracite filters were converted to biofilters by the use of deep bed dual media with gravel support and GAC; and
- A SCADA system to monitor/control all processes and equipment in the facility was installed.

Ozonation and biological filtration began at the SWTP in March, 1998. Details of the two processes are provided below.

Ozonation Details

SWTP has two application points for ozone. First, in pre-ozonation, ozone is applied prior to coagulation, at doses between 3-7 mg/L. In intermediate ozonation, ozone is applied again to settled water at doses between 0.75 - 4.0 mg/L before the water undergoes biological filtration. The ozonation system at the SWTP uses a maximum of 1380 lbs ozone/day.

Biofiltration Details

Specifications for the four new biological filters in the North Plant are as follows:

- Support Gravel - 3"
- Silica Sand - 15"
- GAC - 48"

Specifications for the 12 existing filters in the South Plant which were converted to biological filtration are as follows:

- Support Gravel - 12"
- Silica Sand - 6"
- GAC - 21"

Finished water from the SWTP's storage reservoir is used to backwash the biological filters at both the North and South Plants. At the North Plant, the filters undergo air scouring prior to backwash, and at the South Plant, the filters use surface sweeps prior to backwash.

Results of the Steps Taken

After the upgrades made at the SWTP, the following water quality improvements have been observed.

- TOC reduction from raw water to settled water has been observed, and additional TOC reduction has been observed as result of the biological filtration. Finished water TOC levels have been reduced to 2.0 - 2.5 mg/L;

- TTHM levels have decreased to 60 μg/L (typical level);

- HAA5 levels have decreased from 48.5 μg/L (based on 1997 values) to 21.37 μg/L (based on 1999 values);

- Iron levels have been reduced from 0.9 mg/L (maximum level in source water) to less than 0.020 mg/L (finished water); and

- Manganese levels have been reduced from 0.06 - 4.0 mg/L (range of typical to maximum levels in source water) to less than 0.01 mg/L (finished water).

Implementation and Operational Issues Faced by the Utility

The SWTP switched from disinfection with chlorine/chlorine dioxide to ozone. Although no specific issues were described for the SWTP, the following general issues are relevant to switching to disinfection with ozone.

- Increased costs (due to liquid oxygen, electricity, and higher O&M costs);
- Use of ozone requires a higher level of technical skill from the operators; therefore, increased training may be required; and
- Since ozonation could lead to an increase in the AOC levels in the finished water, biofiltration should be implemented to remove the additional AOC.

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Case Study #12
Ultraviolet Disinfection
Poughkeepsie Water Treatment Facility
Poughkeepsie, New York

This case study provides an example of a water system that installed ultraviolet light (UV) to meet DBP requirements while maintaining compliance with SWTR and IESWTR requirements. By switching to UV, the system also facilitated compliance with the LT2ESWTR requirements for *Cryptosporidium* inactivation.

The information for this case study comes from interviews with water treatment plant staff (Alstadt 2005, Lill 2005) and from the plant's Web site at http://www.pokwater.com. Readers are also encouraged to refer to the *Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule* (USEPA 2006b) for information on UV sensor calibration procedures and practices.

Introduction

Poughkeepsie's Water Treatment Facility (PWTF) is a surface water treatment plant located in Poughkeepsie, New York. The plant uses the Hudson River as a source and has a capacity of 16 MGD. In March 2002 the system began a series of improvements to the plant to increase its rated capacity, ensure continued compliance with existing regulations, and prepare for expected future regulations. In the second quarter of 2003 (May 1 through July 31) the PWTF incurred a violation for exceeding the MCL for HAA5. The system has been in compliance with the MCLs for both HAA5 and TTHM since that date and is completing modifications, including installing UV, to prevent another exceedance.

PWTF is a conventional surface water treatment plant with rapid mix, followed by three parallel trains, each with a solids contact tank and sedimentation followed by filtration. The plant has a total of six filters. An equalization basin succeeds the filters with orthophosphoric acid added in the first half and sodium hydroxide added in the second half. Chlorine is added in the sedimentation basins and again just before the water leaves the treatment plant to maintain a residual in the distribution system.

Simultaneous Compliance Issues Faced by the Utility

The primary issue faced by the system was the need to reduce DBPs. However, in doing so, the system needed to ensure that it could maintain a high enough CT to ensure compliance with the requirements for *Giardia* and viruses. In addition, the LT2ESWTR was expected to contain new requirements for *Cryptosporidium* inactivation. The system needed to consider how any modifications made to address DBPs could impact the system's ability to meet these other requirements.

Steps Taken by the Utility

In order to reduce DBPs, the system proposed moving the point of disinfection from the sedimentation basins to just prior to the filters, after more DBP precursors have been removed. However, in doing so, the system would lose some disinfection contact time. In order to maintain the necessary CT, the system needed to add an additional contact basin after the filters. Due to space limitations, constructing a contact basin large enough to maintain CT was not feasible. Therefore, the system chose to install UV after each filter to provide additional CT and meet space requirements. In addition, UV does not produce any DBPs, so installing UV rather than additional chlorine contact time after the filters would further reduce the system's TTHM and HAA5 levels. The UV installation and all associated modifications have been completed.

An additional benefit of installing UV at the PWTF is that UV has been shown to be an effective technology for inactivating *Cryptosporidium* at a low dose. The use of UV at PWTF should enable the system to meet the *Cryptosporidium* inactivation requirements under the LT2ESWTR.

PWTF is now planning to switch from chlorine to chloramines for secondary disinfection to further reduce DBPs in the distribution system. The system will continue to use chlorine and UV as primary disinfectants, but will begin adding ammonia after the equalization basin to form chloramines. The system expects to begin using chloramines in 2006 after a new flushing program has been implemented.

Expected Results of the Steps Taken

Bench-scale pilot testing indicated that installing UV would reduce TTHM and HAA5 by 20 percent. Pilot testing also showed that addition of chloramines will reduce DBPs by another 80 percent. The UV installation is expected to provide 3-log inactivation of *Giardia* and *Cryptosporidium*, which will ensure that the system maintains compliance with the Giardia inactivation requirements under the IESWTR. In addition, the system should be able to meet the requirements for *Cryptosporidium* under the LT2ESWTR. Because UV is less effective against some kinds of viruses, the system expects that it will need to achieve 1 log of virus inactivation through chlorination after the UV units. The system will meet this requirement with the existing equalization basin.

Implementation and Operational Issues Faced by the Utility

One of the biggest issues for the PWTF staff during the modifications was learning to operate and maintain the UV system. PWTF found that operating a UV system is very different from operating a chemical disinfection system. It is a fairly simple process to determine when a chemical disinfection system is operating properly because the residual can be easily measured with a grab sample. Determining how effectively a UV unit is working is much more complex because there is no measurable residual in the water. In order to determine the UV dose received by organisms in the water, the operator needs to know the intensity delivered by the UV bulbs and the transmittance of the water. The UV reactor contains an array of sensors that are used to determine the intensity and the readings among the sensors can vary significantly, making it difficult to determine which are correct. PWTF staff had problems with many of the intensity sensors in their UV chambers and had to have them replaced. They also had problems with the transmittance meter. These problems had not been resolved as of Fall 2005.

Obtaining appropriate training was also an issue for the system. Although the manufacturer provided some training, the water treatment plant staff had not yet worked with the UV system and were unable to communicate specific training needs to the manufacturer. Therefore, the plant staff found that many operational and maintenance issues arose during installation and testing that were not addressed during training.

Programming the UV system and integrating it into plant controls was difficult. The water treatment plant would have to be shut down if the UV system failed and the control system would need to be programmed to do so. In addition, the UV units require 10 minutes to cool down before shutdown to avoid damage to the UV units. Therefore, PWTF had to install a UPS to hold the power for the UV units for 10 minutes in the event of a power failure. Trying to consider all possible scenarios and how to react to and program them was a complicated process.

Large UV systems require a significant amount of power, particularly at high doses. The UV units at PWTF have all been successfully started up and the system is receiving one (1) log inactivation credit for the UV although the primary disinfectant application point has not yet been moved. With all UV units running, PWTF observed a 20 percent increase in power utilization, which significantly increased the plant's power costs. The new UV system also led to increased maintenance time and costs. The UV system has many components, such as sensors and bulbs, which require periodic replacement. In addition, the monitoring equipment must be calibrated regularly.

Lessons Learned From this Case Study

- UV disinfection is very different from chemical disinfection. It is important that operators undergo training and have continued access to knowledgeable representatives from the manufacturer during installation and start-up of this technology to allow them to become comfortable with the new instrumentation and controls; and

- UV is an effective technology both for reducing DBPs and inactivating *Giardia* and *Cryptosporidium*. However, it also consumes much more electricity than chlorination or chloramination. Therefore, it is important to consider the availability of electricity and the financial impact of increased power usage before installing UV.

References

Alstadt, R. 2005. Personal Communication.

Lill, P. 2005. Personal Communication.

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Case Study #13
Chlorine Dioxide for Primary Disinfection and Chloramines for Secondary Disinfection
Gulf Coast Water Authority
Texas City, TX

This case study provides an example of a water treatment plant with high influent TOC, high bromide, warm water temperatures, and long residence times in the distribution system that converted to chlorine dioxide as a primary disinfectant and chloramines as a secondary disinfectant to reduce the formation of chlorinated DBPs.

The information for this case study was obtained primarily from Krasner et al. (2003). Readers should refer to that text for more detailed information.

Introduction

The Gulf Coast Water Authority (GCWA), which has been operating since 1981, operates the Thomas S. Mackey WTP from which treated water is wholesaled to seven municipalities between Houston and Galveston, TX. All of the systems served by GCWA conduct their own distribution system monitoring for regulatory compliance. Approximately 92,000 people are served by the GCWA in the seven municipalities. Additionally, raw water is pumped to industry and treated water is provided to the City of Houston via pipeline between Houston and Galveston.

The current rated capacity of the Thomas S. Mackey WTP is 25 MGD, with approximate average and maximum flows of 12 and 20 MGD, respectively.

GCWA uses the Brazos River as their source water, which has moderate to high levels of TOC, hardness, alkalinity, and bromide.

A summary of the influent water quality to the GCWA is provided in Exhibit B.25.

Exhibit B.25 Water Quality at GCWA

Water Quality Parameter	Influent Concentration
Turbidity (NTU)	~ 35 (median)
Hardness (mg/L as $CaCO_3$)	190 (median)
pH	8.25 (median)
Alkalinity (mg/L as $CaCO_3$)	135 (median)
TOC (mg/L)	4.7 (median)
Bromide (mg/L)	up to 0.3

The Original Treatment Process at the Gulf Coast Water Authority

Before treatment changes were made at the Thomas S. Mackey WTP, free chlorine was used as a primary disinfectant. The treatment train consisted of the following:

- Raw water pumping
- Chemical addition (including lime softening)
- Upflow solids contact/clarification
- Recarbonation
- Filtration
- Disinfection (with free chlorine)
- Finished water pumping

The Brazos River has moderate to high concentrations of TOC, as well as high bromide concentrations. The Thomas S. Mackey WTP was using chlorine as a disinfectant; therefore, GCWA was facing the challenge of controlling formation of chlorinated and brominated DBPs. Under these conditions, TTHM formation was ranging up to 350 μg/L, and TTHM formation potential (TTHMFP) concentrations were ranging between 800 and 1000 μg/L. These concerns were the main reasons that GCWA changed their disinfection strategy from chlorine to chlorine dioxide.

Simultaneous Compliance Issues Faced by the Utility

Disinfection with chlorine dioxide raised the following compliance issues for GCWA:

- Ensuring that the system was in compliance with SWTR and IESWTR under all operating conditions;

- Ensuring that the Stage 1 DBPR TTHM MCL of 80 μg/L and HAA5 MCL of 60 μg/L were not exceeded; and

- Ensuring that the Stage 1 DBPR chlorine dioxide MRDL of 0.8 mg/L and the chlorite MCL of 1.0 mg/L were not exceeded.

Note, at the time of the treatment train modifications, the plant was initially operating to comply with a TTHM MCL of 100 µg/L and limiting the use of chlorine dioxide to make sure the sum of chlorine dioxide, chlorite, and chlorate did not exceed 1 mg/L.

Steps Taken by the Utility

GCWA conducted eight phases of research before a final decision was made to use chlorine dioxide as both a primary and secondary disinfectant. Exhibit B.26 show the various disinfection strategies implemented at GCWA during the eight phases.

Exhibit B.26 Disinfection Strategies implemented at GCWA

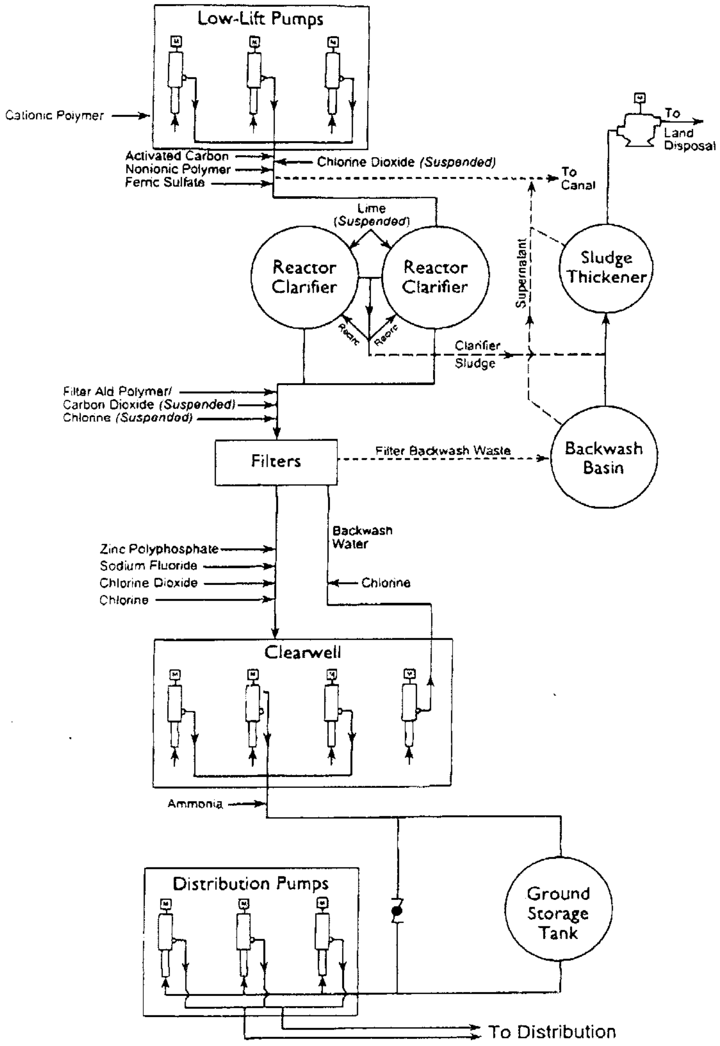
Phase	Dates	Primary Disinfectant	Secondary Disinfectant
1	Prior to 11/83	Chlorine	chlorine
2	11/83	Chloramines	chloramines
3	12/83 - 4/84	Chloramines	chlorine[4]
4	5/84 - 2/85	chlorine dioxide	chlorine
5	3/85 - 4/85	chlorine dioxide	chlorine dioxide
6	5/85 - 11/85	chlorine dioxide	chlorine dioxide/chlorine
7	12/85 - SWTR[1]	chlorine dioxide	chlorine dioxide/ chloramines
8	SWTR - 2003	chlorine dioxide[2]/chlorine dioxide[3]	chloramines

Source: Adapted from Krasner et al., 2003.
Notes:
[1] Disinfection scheme changed after SWTR promulgation
[2] Chlorine dioxide used intermittently as a pre-oxidant in raw water
[3] Chlorine dioxide used as primary disinfectant following filtration
[4] Breakpoint chlorination used to achieve free chlorine residual in distribution system

As shown in Exhibit B.26, the eight phases span more than 20 years. Following promulgation of SWTR, chlorine dioxide was used as a primary disinfectant, which was applied after filtration. Chloramines were used for secondary disinfection. Additionally, chlorine dioxide was also intermittently used as pre-oxidant, which was applied to the raw water.

A process schematic of the treatment train at the Thomas S. Mackey WTP after changes were made is provided in Exhibit B.27.

Exhibit B.27 Schematic of Thomas S. Mackey WTP Treatment TrainAfter Changes Were Made



Source: Krasner et al., 2003.

Results of the Steps Taken

During the disinfection scheme used in phase 8, TTHM concentrations decreased significantly from above 300 µg/L when free chlorine was used as the disinfectant. Disinfection with chlorine dioxide, followed by residual disinfection with chloramines, decreased TTHM concentrations in the GCWA system by approximately 80 percent, to 50 - 70 µg/L.

Stage 1 DBPR set a chlorine dioxide MRDL of 0.8 mg/L and a chlorite MCL of 1.0 mg/L. GCWA is in compliance with these requirements. GCWA applies a chlorine dioxide dose of 0.75 mg/L and, as shown in Exhibit B.28, the chlorite concentration in the treated water is 0.5 mg/L. However, the chlorine dioxide dose applied is not high enough to obtain any CT log removal credit under LT2ESWTR.

The GCWA treated water quality after modifications were made to disinfection is summarized in Exhibit B.28.

Exhibit B.28 Treated Water Quality at GCWA

Water Quality Parameter	Concentration
Turbidity (NTU)	0.14 (median)
Hardness (mg/L as $CaCO_3$)	185 (median)
pH	7.63 (median)
Alkalinity (mg/L as $CaCO_3$)	120 (median)
TOC (mg/L)	2.9 (median)
Bromide (mg/L)	0.11 (median)
TTHM (mg/L) Finished water (clearwell effluent) Customers' distribution system	 36 - 58 50 - 70, (RAA = 55)
Chlorite (mg/L)	0.5 (median)
Chlorate (mg/L)	0.18 (median)

Note: Based on data collected between January 1996 - November 1997. Partial lime softening was discontinued in 1994.

Implementation and Operational Issues Faced by the Utility

Because chlorine dioxide was a new technology at the time GCWA was considering switching disinfectants, they were faced with some technical questions and challenges in the implementation of chlorine dioxide as their primary disinfectant. Most of the technical issues concerned distribution system water quality, and therefore there was need for a full-scale plant study. The main technical issues faced by GCWA are summarized below:

- Effectiveness of disinfection with chlorine dioxide
- Microbial side effects in distribution system
- Production of chlorite as a byproduct of chlorine dioxide generation
- Taste and odor issues related to disinfection with chlorine dioxide

Lessons Learned From this Case Study

- Use of chlorine dioxide can help a system comply with TTHM and HAA5 MCLs; and

- Systems may have trouble providing sufficient *Cryptosporidium* inactivation to satisfy LT2ESWTR toolbox requirements and still meet the chlorine dioxide MRDL and chlorite MCL.

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Case Study #14
Chlorine Dioxide for Primary Disinfection and Chloramines for Residual Disinfection
Village of Waterloo Water Treatment Plant
Waterloo, New York

This case study provides an example of a small surface water system that successfully converted from using chlorine as its primary and residual disinfectant to using chlorine dioxide for primary disinfection and chloramines for residual disinfection. By switching disinfectants, the Village of Waterloo improved its ability to comply with Stage 1 DBPR and Stage 2 DBPR requirements, added protection against *Cryptosporidium*, and improved the system's ability to maintain a disinfectant residual throughout its distribution system. The narrative for this case study borrows from Gell and Bromka (2003). Readers should refer to this paper for more information about the changes made to Waterloo's system.

Introduction

The Village of Waterloo operates a diatomaceous earth (DE) filtration plant that draws water from Seneca Lake in central New York. The original treatment plant design provides a nominal capacity of 2 million gallons per day (MGD), but the system plans to expand its service to neighboring areas. The system currently serves fewer than 10,000 people, but covers a large geographical area.

The DE filtration produces a low turbidity finished water (usually <0.2 NTU) but does not significantly reduce concentrations of DBP precursors. When chlorine was used, DBPs leaving the plant were generally low but increased to levels close to or above the TTHM MCL. The high DBP levels resulted because the distribution system is sufficiently large and retention time sufficiently long that chlorine, NOM, and bromide in the water had several days to react with each other and form high TTHM concentrations.

A summary of Seneca Lake raw water quality is provided in Exhibit B.29.

Exhibit B.29 Seneca Lake Raw Water Quality

Water Quality Parameter	Average	Observed Range
pH	8.1	7.7 - 8.3
total alkalinity (mg/L as $CaCO_3$)	84	69 - 119
total hardness (mg/L as $CaCO_3$)	145	107 - 158
bromide (mg Br^-/L)	0.32	0.28 - 0.50
turbidity (NTU)	0.63	0.21 - 2.21
TOC (mg C/L)	2.74	2.1 - 4.0
DOC (mg C/L)	2.51	1.7 - 3.2
SUVA (L/mg-m)	1.20	0.63 - 3.13
chlorine demand[1] (mg Cl_2/L)	1.24	0.35 - 3.50

Adapted from Gell, R. and Bromka, 2003.

[1] Timeframe for the chlorine demand is 1.5 to 2 hours, depending on how much water is being pumped by the system.

Moderate bromide concentrations in the raw water were causing predominantly brominated THMs to be formed in the finished water. A 1998 survey of distribution system samples showed an average TTHM concentration of 79 μg/L and an average HAA5 concentration of 21 μg/L. TTHM concentrations ranged from 48 to 150 μg/L, with approximately 75 percent of the TTHM being brominated compounds.

At the same time when the Waterloo system was considering treatment modifications to improve water quality, the system was receiving requests from neighboring areas to expand its service area. As a result, modifications made at the treatment plant included upgrades to increase capacity as well as improve water quality.

The Original Treatment Process at the Waterloo WTP

The Village had added potassium permanganate consistently, and PAC/permanganate seasonally, to control zebra mussel growth and taste and odor problems. These were fairly effective at controlling seasonal taste and odor problems, but the Village operators were interested in improving taste and odor treatment for more consistent control.

Chlorine had previously been added after the DE filters and before water entered the clearwell in order to achieve sufficient *Giardia* and virus CT. Chlorine was added again at booster stations in order to maintain a sufficient disinfectant residual throughout the distribution system.

Simultaneous Compliance Issues Faced by the Utility

The Village of Waterloo faced problems complying with both the Stage 1 D/DBPR and the Stage 2 DBPR due to high TTHM concentrations in its distribution system. It was having trouble maintaining a disinfectant residual throughout the distribution system, which is a requirement of the SWTR.

At the same time that the Stage 1 DBPR requirements were introduced, the IESWTR and the LT1ESWTR introduced requirements for the removal of *Cryptosporidium*. Although DE filtration is not effective at removing DBP precursors, the Village of Waterloo wanted to keep its DE filters in use because of their simplicity and performance for *Cryptosporidium* removal. The Village has been monitoring their raw water for *Cryptosporidium* for several years, and no oocysts have been detected.

Steps Taken by the Utility

A pilot study helped the Village realize that installing treatment to remove DBP precursors would not be efficient, because of the low SUVA concentrations in Seneca Lake's water. Since the system uses DE for its filtration step, enhanced coagulation would have required significant modifications to the current filtration process. Moreover, the Waterloo treatment plant's lakefront location limited options for the disposal of waste streams that would have been generated by many of the DBP precursor removal options.

Simulated distribution system testing showed that TTHM and HAA5 concentrations could be lowered significantly if the system changed its residual disinfectant from chlorine to chloramines. This discovery enabled the system to keep its existing DE filtration process by opting for an alternative disinfection strategy.

In addition, by changing its primary disinfectant from chlorine to chlorine dioxide, the Village could simplify its operations by eliminating the use of potassium permanganate for zebra mussel and taste and odor control. Chlorine dioxide is now injected at the intake structure. Furthermore, changing primary disinfectant from chlorine to chlorine dioxide has enabled a smaller clearwell expansion, which has reduced the amount of expensive lakefront real estate needed by the treatment plant.

Chlorine dioxide is added to the intake and maintains a residual throughout the clearwell. Anhydrous ammonia is added immediately after the clearwell into the discharge pipe before water is pumped into the distribution system. A few yards downstream of the ammonia addition point, chlorine gas is injected. Bench scale tests determined the optimum ammonia and chlorine dosages to maintain a total chlorine residual of 2.0 mg/L over several days.

Before converting from free chlorine to chloramines, the Village, with assistance from its consultants, conducted a thorough and successful public notification campaign to inform users of the potential adverse impact of chloramines consumption (primarily for dialysis patients and fish owners). The Village hosted public meetings, placed newspaper articles, and issued notifications that provided the important information.

Results of the Steps Taken

The reductions in TTHM and HAA5 concentrations after the system switched to chlorine dioxide and chloramines exceeded the Water Manager's expectations. In 2002, THM levels were mostly below their detection levels, with one TTHM measurement of 2.1 μg/L in August at the farthest sampling location. HAA5 concentrations in 2002 averaged 8 μg/L. The total chlorine residual has been maintained throughout the distribution system without the use of re-chlorination stations.

The chlorine dioxide dosage ranges from 0.4 to 1.00 mg/L, depending on water temperature. Distribution system chlorite concentrations range from 0.25 to 0.45 mg/L.

The Village has not experienced any uncontrollable re-growth episodes, but uses a carefully monitored program to address the potential for nitrification and biological re-growth. As part of this effort, the Village adheres to the following guidelines:

- Maintain a high chlorine to ammonia weight ratio (5:1) at the time when the chloramines are formed;
- Maintain a finished water total chlorine residual of 2 mg/L and a residual of at least 1.0 mg/L throughout the distribution system;
- Take advantage of the possibility that chlorite, a byproduct of chlorine dioxide disinfection, may be toxic to nitrifying bacteria;
- Monitor monthly for HPC, nitrite, chlorite, free, and total ammonia at each storage tank and at key points in the distribution system; and
- Routinely check the percentage of monochloramine in the total chlorine present. Aim to have at least 95 percent monochloramine leaving the treatment plant.

Since switching disinfectants, the Village has observed two occasions when HPC numbers increased, and traced the cause of these events to stagnation in a remote storage tank. Sodium hypochlorite was added to the tank and HPC levels returned to normal. Plans are being developed to improve mixing in the tanks.

The Water Director believes that previously bothersome taste and odor problems are being controlled more effectively by using chlorine dioxide. He also believes that the use of chloramines following chlorine dioxide has prevented the development of nuisance odors associated with chlorine dioxide in households (see Hoehn et al., 1990).

Implementation and Operational Issues Faced by the Utility

The Village encountered an operational problem when it first converted to chloramines. Ammonia reacts with calcium and magnesium hardness in the water and produces a scale, even when hardness values are as low as 35 mg/L as $CaCO_3$. As a result, scaling was clogging the injector throat of the ammonia feed system. Since a water softening unit was installed to treat the water that is used for injection, the ammonia feed system has functioned reliably.

The Village has a service contract with the company that provided the chlorine dioxide equipment to supply sodium chlorite and monitor and verify the performance of the generator. This contract has provided the Village with sufficient time to educate its staff on proper equipment operation.

Further Reading

Readers who are interested in learning more about the Village of Waterloo system should refer to the following paper:

> Gell, R. and J. Bromka. 2003. *Successful Application of Chloramines to Manage Disinfection By-Products.* New York State Section AWWA. New York: O'Brien and Gere.

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Appendix C

Guidance for Evaluating Potential Impacts of Treatment Changes on Distribution Systems

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Appendix C
Guidance for Evaluating Potential Impacts of Treatment Changes on Distribution Systems

This appendix is designed to accompany the guidance manual and provides a starting point for examining issues that might arise in the distribution system as a result of treatment changes. Water systems are encouraged to use this document to identify potential issues for their system and possible solutions to those issues. This guidance manual and its appendices, however, are not intended to provide comprehensive technical guidance for systems making regulatory compliance decisions and treatment modifications. Each state may have its own rules and regulations pertaining to treatment modifications. Systems should contact their state primacy agency or EPA regional office for more information.

The table below lists treatment changes that could potentially impact the distribution system and page numbers in this appendix where the potential impacts of particular treatment changes are discussed. A list of references is also included for each distribution system impact.

Treatment Change	**See Appendix Page**
Modifying pH	C-2
Change in finished water alkalinity	C-7
Change in finished water oxidation/reduction potential	C-10
Switching from chlorine to chloramines	C-11
Switching coagulant	C-15
Modifying chlorine dose with warmer water temperatures	C-17
Adding/discontinuing softening	C-18
Adding ozone	C-22
Adding chlorine dioxide	C-25
Enhanced coagulation	C-28
Installing nanofiltration	C-30
Installing granular activated carbon	C-33
Installing ozone without subsequent biological filtration	C-34

MODIFYING pH

The following impacts to your distribution system may result from modifying pH:

- Increased lead and copper in tap water
- Change/disruption of scale
- Colored water
- High iron
- Increased heterotrophic bacteria
- Nitrite/nitrate formation
- Change in DBP concentration/composition

References, along with brief descriptions of treatment impacts, are provided below. Refer to Section 3.4 for additional information on modifying pH during chlorination.

Increased lead and copper in tap water

Description

As the pH of water decreases, the corrosion potential of the water increases. Therefore, a significant decrease in finished water pH may result in a significant increase in corrosion of distribution system pipes, resulting in increased concentrations of metals such as iron, copper, and lead in the water. In addition, if the pH of the water is too low, protective scales may be disrupted or unable to form on pipe surfaces.

Further Reading

- USEPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual. EPA 815-R-99-011. August 1999.
- USEPA. 2000c. Lead and Copper Rule: Summary of Revisions. Office of Water. EPA 815-R-99-020.
- USEPA. 2003h. Revised Guidance Manual for Selecting Lead and Copper Control Strategies. Office of Water. EPA 816-R-03-001. March, 2003.
- AwwaRF and DVGW-Technologiezentrum Wasser. 1996. *Internal Corrosion of Water Distribution Systems.* 2nd edition. AwwaRF Report 90508. Project #725. Denver: AwwaRF.
- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. *Optimizing Corrosion Control in Distribution Systems.* AwwaRF Report 90983. Project #2648. Denver: AwwaRF.

Change/disruption of scale

Description

When water is supersaturated with calcium carbonate, the calcium carbonate can precipitate in the distribution system and form a coating on pipes that protects against corrosion. The pH of the water plays a major role in the solubility of calcium carbonate. If the pH in the distribution system is too low, calcium carbonate becomes undersaturated, causing scales to change or become dislodged. Scales can also form in the distribution system from corrosion byproducts. Because corrosion (and subsequently formation of these scales) is partially dependent on pH, these scales can also be disrupted by changes in pH.

Further Reading

- AWWA. 1999c. *Water Quality and Treatment: A Handbook of Community Water Supplies*. 5th Edition. Letterman, R.D. (editor). 1,233 pp. New York: McGraw-Hill.
- USEPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual. EPA 815-R-99-011. August 1999.
- AwwaRF and DVGW-Technologiezentrum Wasser. 1996. *Internal Corrosion of Water Distribution Systems.* 2nd edition. AwwaRF Report 90508. Project #725. Denver: AwwaRF.
- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. *Optimizing Corrosion Control in Distribution Systems.* AwwaRF Report 90983. Project #2648. Denver: AwwaRF.
- Smith, C.D. (editor). 2005. *Water Distribution System Assessment Workbook*. 85 pp. Denver: AWWA.

Colored water

Description

A decrease in pH can lead to increased corrosion and increased solubility of inorganics, which may result in increased iron and copper levels. A change in pH can also cause disruption of scales. Increased iron levels and disruption of scale containing iron corrosion byproducts can cause red water. Increased copper levels can cause blue or green water.

Further Reading

- USEPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual. EPA 815-R-99-011. August 1999.
- White, G.C. 1999. *Handbook of Chlorination and Alternative Disinfectants*. 4th Edition. New York: Van Nostrand Reinhold Co.
- Connell, G. 1996. *The Chlorination/Chloramination Handbook*. 174 pp. Denver: AWWA.
- Von Huben, H. 1999. *Water Distribution Operator Training Handbook.* 2nd Edition.278 pp. Denver: AWWA.
- AWWA. 2003a. *Principles and Practices of Water Supply Operations: Water Transmission and Distribution*. 3rd Edition. 553 pp. Denver: AWWA.
- Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality.* AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
- Mays, L.W. 1999. *Water Distribution Systems Handbook*. 900 pp. Denver: AWWA.

High iron
Description A decrease in pH can lead to increased corrosion and increased solubility of inorganics, which may result in increased iron levels when iron pipe is used. A change in pH can also cause disruption of scales. If the scales contain corrosion byproducts, the iron levels in the water can be further increased.
Further Reading • USEPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual. EPA 815-R-99-011. August 1999. • White, G.C. 1999. *Handbook of Chlorination and Alternative Disinfectants*. 4th Edition. New York: Van Nostrand Reinhold Co. • Connell, G. 1996. *The Chlorination/Chloramination Handbook*. 174 pp. Denver: AWWA. • Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. *Optimizing Corrosion Control in Distribution Systems.* AwwaRF Report 90983. Project #2648. Denver: AwwaRF.
Increased heterotrophic bacteria
Description Films and scales can build up on distribution system pipes and may contain microorganisms as well as inorganic contaminants and TOC. If the pH fluctuates below 7.0 in the distribution system, these scales may become dislodged. This would allow the release of the trapped microorganisms into the distribution system, thereby increasing their numbers in the water.
Further Reading • White, G.C. 1999. *Handbook of Chlorination and Alternative Disinfectants*. 4th Edition. New York: Van Nostrand Reinhold Co. • Connell, G. 1996. *The Chlorination/Chloramination Handbook*. 174 pp. Denver: AWWA. • Von Huben, H. 1999. *Water Distribution Operator Training Handbook*. 2nd Edition. 278 pp. Denver: AWWA. • AWWA. 2003a. *Principles and Practices of Water Supply Operations: Water Transmission and Distribution*. 3rd Edition. 553 pp. Denver: AWWA. • Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality.* AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA. • Lauer, W.C. 2005. *Water Quality in the Distribution System*. Denver: AWWA. • Mays, L.W. 1999. *Water Distribution Systems Handbook*. 900 pp. Denver: AWWA. • Smith, C.D. (editor). 2005. *Water Distribution System Assessment Workbook*. 85 pp. Denver: AWWA.

Nitrite/nitrate formation

Description

The optimum pH for nitrification to occur is between 7.5 and 8.5. If systems using chloramines make changes resulting in a finished water pH in this range, these systems may have problems with nitrification in the distribution system, causing increased levels of nitrite and nitrate.

Further Reading

- Harrington, G.W., D.R. Noguera, C.C. Bone, A.I. Kandou, P.S. Oldenburg, J.M. Regan, and D. Van Hoven. 2003. *Ammonia from Chloramine Decay: Effects on Distribution System Nitrification.* AwwaRF Report 90949. Project #553. Denver: AwwaRF.
- Kirmeyer, G.J., M. LeChevallier, H. Barbeau, K. Martel, G. Thompson, L. Radder, W. Klement, and A. Flores. 2004a. *Optimizing Chloramine Treatment*. 2nd Edition. AwwaRF Report 90993. Project #2760. Denver: AwwaRF.
- Kirmeyer, G.J., L.H. Odell, J. Jacangelo, A. Wilczak, and R. Wolfe. 1995. *Nitrification Occurrence and Control in Chloraminated Water Systems*. AwwaRF Report 90669. Project #710. Denver: AwwaRF.
- White, G.C. 1999. *Handbook of Chlorination and Alternative Disinfectants*. 4th Edition. New York: Van Nostrand Reinhold Co.
- Cowman, G.A., and P.C. Singer. 1994. Effect of Bromide Ion on Haloacetic Acid Speciation Resulting from Chlorination and Chloramination of Humic Extracts. In *Proceedings of AWWA Annual Conference*. New York, NY.
- Connell, G. 1996. *The Chlorination/Chloramination Handbook*. 174 pp. Denver: AWWA.
- USEPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014.
- Von Huben, H. 1999. *Water Distribution Operator Training Handbook*. 2nd Edition.278 pp. Denver: AWWA.
- AWWA. 2003a. *Principles and Practices of Water Supply Operations: Water Transmission and Distribution*. 3rd Edition. 553 pp. Denver: AWWA.
- Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality.* AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
- Lauer, W.C. 2005. *Water Quality in the Distribution System*. Denver: AWWA.
- Mays, L.W. 1999. *Water Distribution Systems Handbook*. 900 pp. Denver: AWWA.
- Smith, C.D. (editor). 2005. *Water Distribution System Assessment Workbook*. 85 pp. Denver: AWWA.

Change in DBP concentration/composition

Description

Reducing the pH of the water may allow systems to use a lower chlorine concentration for disinfection, leading to less DBP formation. Since TTHMs generally show lower formation at lower pH, reducing the pH can also lead to lower TTHM levels. However, HAA5s generally show higher formation at lower pH, so the HAA5 levels may increase.

Further Reading

- White, G.C. 1999. *Handbook of Chlorination and Alternative Disinfectants*. 4th Edition. New York: Van Nostrand Reinhold Co.
- Connell, G. 1996. *The Chlorination/Chloramination Handbook*. 174 pp. Denver: AWWA.
- USEPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014.
- Von Huben, H. 1999. *Water Distribution Operator Training Handbook*. 2nd Edition.278 pp. Denver: AWWA.
- AWWA. 2003a. *Principles and Practices of Water Supply Operations: Water Transmission and Distribution*. 3rd Edition. 553 pp. Denver: AWWA.
- Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality.* AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
- Lauer, W.C. 2005. *Water Quality in the Distribution System*. Denver: AWWA.
- Mays, L.W. 1999. *Water Distribution Systems Handbook*. 900 pp. Denver: AWWA.
- Smith, C.D. (editor). 2005. *Water Distribution System Assessment Workbook*. 85 pp. Denver: AWWA.

CHANGE IN FINISHED WATER ALKALINITY

The following impacts to your distribution system may result from changes in finished water alkalinity:

- Increased lead and copper in tap water
- Change/disruption of scale
- Colored water
- High iron
- Pinhole leaks

The following reference can provide further information about how to address most of these impacts. Additional references and brief descriptions are listed by impact in the table below.

- AwwaRF and DVGW-Technologiezentrum Wasser. 1996. *Internal Corrosion of Water Distribution Systems.* 2nd Edition. AwwaRF Report 90508. Project #725. Denver: AwwaRF.

Refer to Sections 3.4 and 3.7 for additional information on changes in finished water alkalinity.

Increased lead and copper in tap water
Description When alkalinity is removed, the carbonate system must re-equilibrate, resulting in the production of the hydrogen ion. This in turn results in a lowering of the pH of the water. In addition, as alkalinity decreases, the buffering capacity of the water decreases, allowing the pH of the water to change more easily during treatment processes. However, when the alkalinity and pH are high, lead corrosion can also increase as a result of increased lead solubility and lead complexation with carbonate (AWWA 1999d). Therefore, both increases and decreases in finished water alkalinity can increase lead levels in tap water. Copper levels can also increase because bicarbonate is extremely aggressive toward copper (AWWA 1999d).
Further Reading • AWWA. 1999c. *Water Quality and Treatment: A Handbook of Community Water Supplies*. 5th Edition. Letterman, R.D. (editor). New York: McGraw-Hill. • AWWA. 2005a. *Managing Change and Unintended Consequences: Lead and Copper Rule Corrosion Control Treatment.* Denver: AWWA. • Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. *Optimizing Corrosion Control in Distribution Systems.* AwwaRF Report 90983. Project #2648. Denver: AwwaRF.

Change/disruption of scale

Description

Alkalinity is a measure of the carbonate and bicarbonate in water. When calcium ions combine with carbonate in water it can precipitate out to form a protective coating on pipes in the distribution system. If the alkalinity in the water is subsequently reduced, some of the calcium carbonate may re-dissolve in the water, disrupting the protective scale on the pipes, which can lead to increased corrosion or release of scales and corrosion by-products. Lowered alkalinity can also lead to increased leaching from cement/mortar lined pipes. In addition, when alkalinity is reduces, the pH in the water can fluctuate more easily. Fluctuations in pH can in turn disrupt scales in the distribution system.

Further Reading

- AWWA. 1990. *Water Quality and Treatment*. F.W. Pontius (editor). New York: McGraw-Hill.
- USEPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual. EPA 815-R-99-011. August 1999.
- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. *Optimizing Corrosion Control in Distribution Systems.* AwwaRF Report 90983. Project #2648. Denver: AwwaRF.
- Smith, C.D. (editor). 2005. *Water Distribution System Assessment Workbook*. 85 pp. Denver: AWWA.
- Douglas, B.D., and D.T. Merrill. 1991. *Control of Water Quality Deterioration Caused by Corrosion of Cement-Mortar Pipe Linings*. Denver: AwwaRF

Colored water

Description

A decrease in alkalinity can result in a lowering of the pH of the water. The buffering capacity of the water also decreases, allowing the pH of the water to change more easily during treatment processes and in the distribution system. Decreased pH can lead to increased corrosion of iron pipe. In addition, decreased alkalinity can cause disruption of protective pipe scales, which can lead to further corrosion. Corrosion byproducts in the water can cause colored water problems.

Further Reading

- AWWA. 1990. *Water Quality and Treatment*. F.W. Pontius (editor). New York: McGraw-Hill.
- Von Huben, H. 1999. *Water Distribution Operator Training Handbook*. 2nd Edition.278 pp. Denver: AWWA.
- AWWA. 2003a. *Principles and Practices of Water Supply Operations: Water Transmission and Distribution*. 3rd Edition. 553 pp. Denver: AWWA.
- Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality.* AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
- Mays, L.W. 1999. *Water Distribution Systems Handbook*. 900 pp. Denver: AWWA.

High iron

Description

A decrease in alkalinity can result in a lowering of the pH of the water. The buffering capacity of the water also decreases, allowing the pH of the water to change more easily during treatment processes. Decreased pH can lead to increased corrosion of pipes. In addition, decreased alkalinity can cause disruption of protective pipe scales, which can lead to further corrosion. If iron pipe is present in the distribution system, increased corrosion can lead to higher iron levels in the water.

Further Reading

- AWWA. 1990. *Water Quality and Treatment*. F.W. Pontius (editor). New York: McGraw-Hill.
- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. *Optimizing Corrosion Control in Distribution Systems.* AwwaRF Report 90983. Project #2648. Denver: AwwaRF.

Pinhole leaks

Description

Changes in finished water alkalinity and resulting changes in pH can cause water to become more corrosive to copper piping, especially in the absence of corrosion inhibitors such as phosphate or NOM.

Further Reading

- Edwards, M., J.C. Rushing, S. Kvech, and S. Reiber. 2004. Assessing copper pinhole leaks in residential plumbing. *Water Science and Technology*. 49(2): 83-90.
- Edwards, M., J.F. Ferguson, S. Reiber. 1994. The Pitting Corrosion of Copper. *Journal of American Water Works Association*. 86(7): 74-91.

CHANGE IN FINISHED WATER OXIDATION/REDUCTION POTENTIAL

Oxidation/reduction potential (ORP) is the ability of the water to oxidize or reduce compounds it comes into contact with, and is measured electrochemically. If a treatment change causes a change in finished water ORP, you could possibly experience increased lead in tap water or a change or disruption of corrosion scales.

The following references can provide further information about how to address both of these impacts. Additional references and brief descriptions are listed by impact in the table below.

- AwwaRF and DVGW-Technologiezentrum Wasser. 1996. *Internal Corrosion of Water Distribution Systems.* 2nd edition. AwwaRF Report 90508. Project #725. Denver: AwwaRF.
- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. *Optimizing Corrosion Control in Distribution Systems.* AwwaRF Report 90983. Project #2648. Denver: AwwaRF.

Refer to Section 5.1 for additional information on changes to finished water oxidation/reduction potential.

Increased lead in tap water
Description Raising or lowering the ORP can affect the redox state of any corrosion products existing in passivating layers in the distribution system. As the solubility of lead changes with its redox state, this can lead to solublization of lead and its release into tap water. Ammonia and nitrate can increase leaching of lead from materials such as brass.
Further Reading • AWWA. 2004d. Proceedings of Workshop - *Getting the Lead Out: Analysis & Treatment of Elevated Lead Levels in DC's Drinking Water.* San Antonio: WQTC. • Lytle, D.A. and M.R. Schock. 2005. The Formation of Pb(IV) Oxides in Chlorinated Water. *Journal of American Water Works Association*. 97(11):102. • Schock, M.R., K.G. Scheckel, M. DeSantis, and T.L. Gerke. 2005. Mode of Occurrence, Treatment and Monitoring Significance of Tetravalent Lead. In *Proceedings of the AWWA Water Quality Technology Conference.* Denver: AWWA.
Change/disruption of scale
Description Changing the ORP of the finished water will affect the oxidation/reduction equilibrium between the pipe surface and the water. Oxidation/reduction reactions may occur at the pipe surface to enable oxidation/reduction equilibrium to be achieved. If these reactions alter any passivating layers, dissolution and release of metals may occur.
Further Reading • AWWA. 2005a. *Managing Change and Unintended Consequences: Lead and Copper Rule Corrosion Control Treatment.* Denver: AWWA. • Smith, C.D. (editor). 2005. *Water Distribution System Assessment Workbook*. 85 pp. Denver: AWWA.

SWITCHING FROM CHLORINE TO CHLORAMINES

The following impacts to your distribution system may result from switching from chlorine to chloramines:

- Increased lead in tap water
- Change/disruption of scale
- Taste and odor
- Increased coliform bacteria
- Increased heterotrophic bacteria
- Nitrite/nitrate formation
- Change in DBP concentration/composition

The following references can provide further information about how to address most of these impacts. Additional references and brief descriptions are listed by impact in the table below.

- Von Huben, H. 1999. *Water Distribution Operator Training Handbook.* 2nd Edition. 278 pp. Denver: AWWA.
- USEPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014.

Refer to Section 5.1 for additional information on switching from chlorine to chloramines.

Increased lead in tap water
Description The use of chloramines can lead to nitrification in the distribution system. This in turn can lower the pH of the water and increase its corrosivity, causing increased levels of metals such as lead, copper, and iron in water in the distribution system. In addition, because chloramines have a lower oxidation potential than chlorine, switching from chlorine to chloramines is suspected to cause lead in pipes to change to a form that is more soluble. This can also increase the lead concentration in the water in the distribution system.
Further Reading • AwwaRF and DVGW-Technologiezentrum Wasser. 1996. *Internal Corrosion of Water Distribution Systems.* 2nd edition. AwwaRF Report 90508. Project #725. Denver: AwwaRF. • Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. *Optimizing Corrosion Control in Distribution Systems*. AwwaRF Report 90983. Project #2648. Denver: AwwaRF

Change/disruption of scale

Description

The use of chloramines can lead to nitrification in the distribution system. Nitrification can lower the pH of the water, causing disruption to scales formed from corrosion byproducts or protective scales, such as calcium carbonate.

Further Reading

- USEPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual. EPA 815-R-99-011. August 1999.
- AWWA. 1990. *Water Quality and Treatment*. F.W. Pontius (editor). New York: McGraw-Hill.
- AwwaRF and DVGW-Technologiezentrum Wasser. 1996. *Internal Corrosion of Water Distribution Systems.* 2nd edition. AwwaRF Report 90508. Project #725. Denver: AwwaRF.
- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. *Optimizing Corrosion Control in Distribution Systems*. AwwaRF Report 90983. Project #2648. Denver: AwwaRF.
- Smith, C.D. (editor). 2005. *Water Distribution System Assessment Workbook*. 85 pp. Denver: AWWA.

Taste and odor

Description

Monochloramine is a preferred chlorine residual with regard to odor quality and customer perceptions. Dichloramine can add a more pungent, sharper chlorine-type odor to the water at lower levels such that some utilities have set a goal to keep the percentage dichloramine of the total combined chlorine residual below 20% (ref. Lines 11-12 page 7-6). Monochloramine is preferred over free chlorine as it takes a higher level to reach odor detection by customers, and changes in odor following changes in the residual are much less noticeable by customers. However, there have been reports of off-odors associated with nitrification, which could come from biological growth, loss of chloramine residual, and related conditions.

Further Reading

- Singer, P.C. (editor). 1999. *Formation and Control of Disinfection By-Products in Drinking Water*. 424 pp. Denver: AWWA.
- AWWA. 2003a. *Principles and Practices of Water Supply Operations: Water Transmission and Distribution*. 3rd Edition. 553 pp. Denver: AWWA.
- Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality.* AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
- Lauer, W.C. 2005. *Water Quality in the Distribution System*. Denver: AWWA.
- Mays, L.W. 1999. *Water Distribution Systems Handbook*. 900 pp. Denver: AWWA.

Increased coliform bacteria

Description

The use of chloramines can lead to nitrification in the distribution system. The nitrite formed through nitrification exerts a high chlorine demand, which will rapidly deplete the disinfectant residual (Cowman and Singer 1994). When the disinfectant residual is low or depleted, microorganisms such as coliforms and heterotrophic bacteria can proliferate.

Further Reading

- White, G.C. 1999. *Handbook of Chlorination and Alternative Disinfectants*. 4th Edition. New York: Van Nostrand Reinhold Co.
- Kirmeyer, G.J., L.H. Odell, J. Jacangelo, A. Wilczak, and R. Wolfe. 1995. *Nitrification Occurrence and Control in Chloraminated Water Systems*. AwwaRF Report 90669. Project #710. Denver: AwwaRF.
- Connell, G. 1996. *The Chlorination/Chloramination Handbook*. 174 pp. Denver: AWWA.
- AWWA. 2003a. *Principles and Practices of Water Supply Operations: Water Transmission and Distribution*. 3rd Edition. 553 pp. Denver: AWWA.
- Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality*. AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
- Lauer, W.C. 2005. *Water Quality in the Distribution System*. Denver: AWWA.
- Mays, L.W. 1999. *Water Distribution Systems Handbook*. 900 pp. Denver: AWWA.
- Smith, C.D. (editor). 2005. *Water Distribution System Assessment Workbook*. 85 pp. Denver: AWWA.

Increased heterotrophic bacteria

Description

The use of chloramines can lead to nitrification in the distribution system. The nitrite formed through nitrification exerts a high chlorine demand, which will rapidly deplete the disinfectant residual (Cowman and Singer 1994). When the disinfectant residual is low or depleted, microorganisms such as coliforms and heterotrophic bacteria can proliferate.

Further Reading

- White, G.C. 1999. *Handbook of Chlorination and Alternative Disinfectants*. 4th Edition. New York: Van Nostrand Reinhold Co.
- Cowman, G.A. and P.C. Singer. 1994. Effect of Bromide Ion on Haloacetic Acid Speciation Resulting from Chlorination and Chloramination of Humic Extracts. In *Proceedings of AWWA Annual Conference*. New York, NY.
- Connell, G. 1996. *The Chlorination/Chloramination Handbook*. 174 pp. Denver: AWWA.
- AWWA. 2003a. *Principles and Practices of Water Supply Operations: Water Transmission and Distribution*. 3rd Edition. 553 pp. Denver: AWWA.
- Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality*. AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
- Lauer, W.C. 2005. *Water Quality in the Distribution System*. Denver: AWWA.
- Mays, L.W. 1999. *Water Distribution Systems Handbook*. 900 pp. Denver: AWWA.
- Smith, C.D. (editor). 2005. *Water Distribution System Assessment Workbook*. 85 pp. Denver: AWWA.

Nitrite/nitrate formation

Description

Nitrification can occur when chloramines are used to maintain a residual in the distribution system due to the presence of ammonia, which is used to form chloramines. Nitrifying bacteria convert the excess ammonia into nitrite and nitrate. Nitrification is not a problem when chlorine is used to maintain a residual, because no ammonia is used.

Further Reading

- Kirmeyer, G.J., L.H. Odell, J. Jacangelo, A. Wilczak, and R. Wolfe. 1995. *Nitrification Occurrence and Control in Chloraminated Water Systems*. AwwaRF Report 90669. Project #710. Denver: AwwaRF.
- Connell, G. 1996. *The Chlorination/Chloramination Handbook*. 174 pp. Denver: AWWA.
- AWWA. 2003a. *Principles and Practices of Water Supply Operations: Water Transmission and Distribution*. 3rd Edition. 553 pp. Denver: AWWA.
- Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality.* AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
- Kirmeyer, G.J., M. LeChevallier, H. Barbeau, K. Martel, G. Thompson, L. Radder, W. Klement, and A. Flores. 2004a. *Optimizing Chloramine Treatment.* 2nd Edition. AwwaRF Report 90993. Project #2760. Denver: AwwaRF.
- Lauer, W.C. 2005. *Water Quality in the Distribution System*. Denver: AWWA.
- Cowman, G.A. and P.C. Singer. 1994. Effect of Bromide Ion on Haloacetic Acid Speciation Resulting from Chlorination and Chloramination of Humic Extracts. In *Proceedings, AWWA Annual Conference*. New York, NY.
- Harrington, G.W., D.R. Noguera, C.C. Bone, A.I. Kandou, P.S. Oldenburg, J.M. Regan, and D. Van Hoven. 2003. *Ammonia from Chloramine Decay: Effects on Distribution System Nitrification*. AwwaRF Report 90949. Project #553. Denver: AwwaRF.
- Mays, L.W. 1999. *Water Distribution Systems Handbook*. 900 pp. Denver: AWWA.
- Smith, C.D. (editor). 2005. *Water Distribution System Assessment Workbook*. 85 pp. Denver: AWWA.
- White, G.C. 1999. *Handbook of Chlorination and Alternative Disinfectants*. 4th Edition. New York: Van Nostrand Reinhold Co.

Change in DBP concentration/composition

Description

Chloramines react more slowly with organic matter than free chlorine does. Therefore, switching from chlorine to chloramines can significantly reduce DBP formation. However, it will not completely eliminate DBP formation - TTHM and HAA5 will still be formed, though this formation may be undetectable, largely as a result of excess free chlorine or the hydrolysis of monochloramine to from free chlorine.

Further Reading

- USEPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual. EPA 815-R-99-011. August 1999.
- Smith, C.D. (editor). 2005. *Water Distribution System Assessment Workbook*. 85 pp. Denver: AWWA.
- Valentine, R. 2001. *Mechanisms and Kinetics of Chloramine Loss and By-Product Formation in the Presence of Reactive Drinking Water Distribution System Constituents*. Washington, D.C.: USEPA.

SWITCHING COAGULANT

The following impacts to your distribution system may result from switching your coagulant:

- Change in finished water pH
- Increased lead and copper in tap water
- Change/disruption of scale
- Change in finished water NOM
- Change in chloride:sulfate ratio

The following references can provide further information about how to address most of these impacts. Additional references and brief descriptions are listed by impact in the table below.

- USEPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual. EPA 815-R-99-011. August 1999.
- USEPA. 1999h. Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual. Office of Water. EPA 815-R-99-012.

Refer to Sections 3.3 and 3.7 for additional information on switching coagulants.

Change in finished water pH

Description

Different coagulants have different optimum pH ranges. Therefore, when switching coagulants, it may be necessary to adjust the pH to achieve maximum contaminant removal. In addition, some coagulants consume alkalinity, which results in decreased buffering capacity and allows the pH to change more easily.

Further Reading

- Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality.* AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
- Mays, L.W. 1999. *Water Distribution Systems Handbook*. 900 pp. Denver: AWWA.

Increased lead and copper in tap water

Description

The optimal pH range for coagulants varies by coagulant. Therefore, switching coagulants can require a pH change, and if the pH is significantly reduced, can lead to increased lead and copper corrosion in the distribution system.

Further Reading

- USEPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014.
- AwwaRF and DVGW-Technologiezentrum Wasser. 1996. *Internal Corrosion of Water Distribution Systems*. 2nd edition. AwwaRF Report 90508. Project #725. Denver: AwwaRF.
- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. *Optimizing Corrosion Control in Distribution Systems*. AwwaRF Report 90983. Project #2648. Denver: AwwaRF.

Change/disruption of scale

Description

The optimal pH range for coagulants varies by coagulant. Therefore, switching coagulants can require a change in the operating pH, and consequently, in the distribution system. A higher pH can decrease the rate of corrosion, thereby decreasing the formation of scales from corrosion byproducts. A higher pH can also allow the formation of a protective calcium carbonate scale. A lower pH can cause disruption or dislodgement of scales formed from corrosion byproducts or protective scales, such as calcium carbonate.

Further Reading

- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. *Optimizing Corrosion Control in Distribution Systems*. AwwaRF Report 90983. Project #2648. Denver: AwwaRF.
- Smith, C.D. (editor). 2005. *Water Distribution System Assessment Workbook*. 85 pp. Denver: AWWA.

Change in finished water NOM

Description

To accomplish enhanced coagulation, systems may switch coagulants to improve removal of TOC, which is a surrogate measure of NOM. Therefore, the NOM entering the distribution system is significantly reduced. Some NOM in the finished water can help inhibit corrosion.

Further Reading

- Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality.* AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
- Lauer, W.C. 2005. *Water Quality in the Distribution System*. Denver: AWWA.

Change in chloride:sulfate ratio

Description

Some coagulants, such as aluminum sulfate (alum) and ferric sulfate add sulfate to the water. Other coagulants, such as ferric chloride add chloride to the water. Therefore, switching to or from any of these coagulants can affect the chloride to sulfate ratio. A shift in the sulfate to chloride ratio can cause increased lead and copper corrosion and can alter iron corrosion in the distribution system.

Further Reading

- Lauer, W.C. 2005. *Water Quality in the Distribution System*. Denver: AWWA.

MODIFYING CHLORINE DOSE WITH WARMER WATER TEMPERATURES

The following impacts to your distribution system may result from reducing chlorine dose during warmer water temperatures in order to reduce DBP formation:

- Increased coliform and heterotrophic bacteria
- Increased loss of chlorine residual in the distribution system

The following references can provide further information about how to address this distribution system impact:

- White, G.C. 1999. *Handbook of Chlorination and Alternative Disinfectants*. 4th Edition. New York: Van Nostrand Reinhold Co.
- Connell, G. 1996. *The Chlorination/Chloramination Handbook*. 174 pp. Denver: AWWA.
- Von Huben, H. 1999. *Water Distribution Operator Training Handbook.* 2nd Edition. 278 pp. Denver: AWWA.
- AWWA. 2003a. *Principles and Practices of Water Supply Operations: Water Transmission and Distribution*. 3rd Edition. 553 pp. Denver: AWWA.
- Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesen, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality*. AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
- Lauer, W.C. 2005. *Water Quality in the Distribution System*. Denver: AWWA.
- Mays, L.W. 1999. *Water Distribution Systems Handbook*. 900 pp. Denver: AWWA.
- Smith, C.D. (editor). 2005. *Water Distribution System Assessment Workbook*. 85 pp. Denver: AWWA.
- USEPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014.

Increased coliform and heterotrophic bacteria
Description Chlorine is a more effective disinfectant at higher temperatures. However, because it reacts more quickly at warmer temperatures, the chlorine residual may dissipate more quickly in the distribution system, leaving low or no residual near the end of the distribution system. This can allow increased microbial growth in these areas. In addition, the growth rate of microorganisms is more rapid at higher temperatures, making them more difficult to control. These factors can lead to increased coliform and heterotrophic bacteria if the chlorine dose is lowered during warmer water temperatures.
Increased loss of chlorine residual
Description Lowering the chlorine dose will mean that there is less residual in the distribution system. Higher temperatures will also cause reactions of the residual with chlorine demand to proceed faster.

ADDING/DISCONTINUING SOFTENING

The following impacts to your distribution system may result from adding or discontinuing softening:

- Change in finished water pH
- Increased lead and copper in tap water
- Change/disruption of scale
- Taste and color problems
- Change in finished water NOM
- High iron
- Change in DBP concentration/composition
- Pinhole leaks

The following reference can provide further information about how to address all of these impacts. Additional references and brief descriptions are listed by impact in the table below.

- USEPA. 1999h. Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual. Office of Water. EPA 815-R-99-012.

Refer to Section 3.8 for additional information on adding or discontinuing softening.

Change in finished water pH

Description

In enhanced softening, the pH of the water is typically raised to a value above 10. However, most other water treatment processes are operated at much lower pHs. Therefore, when switching to enhanced softening, systems can expect to have a much higher finished water pH. Conversely, if a system switches from enhanced softening to another technology, the operating and finished water pH will be much lower.

Further Reading

- Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality.* AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
- Mays, L.W. 1999. *Water Distribution Systems Handbook*. 900 pp. Denver: AWWA.

Increased lead and copper in tap water

Description

In enhanced softening, the pH of the water is typically raised to a value above 10. However, most other water treatment processes are operated at much lower pHs. Therefore, when discontinuing softening, systems can expect to have a much lower finished water pH. As the pH decreases, systems can expect an increase in corrosion of distribution system pipes, resulting in increased concentrations of metals such as iron, copper, and lead in the water.

Further Reading

- AwwaRF and DVGW-Technologiezentrum Wasser. 1996. *Internal Corrosion of Water Distribution Systems.* 2nd edition. AwwaRF Report 90508. Project #725. Denver: AwwaRF.
- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. *Optimizing Corrosion Control in Distribution Systems.* AwwaRF Report 90983. Project #2648. Denver: AwwaRF.

Change/disruption of scale

Description

Installing softening requires an increase in operating pH, while discontinuing softening requires a reduction in pH. A higher pH can decrease the rate of corrosion, thereby decreasing the formation of scales from corrosion byproducts. A higher pH can also allow the formation of a protective calcium carbonate scale. A lower pH can cause disruption or dislodgement of scales formed from corrosion byproducts or protective scales, such as calcium carbonate.

Further Reading

- AwwaRF and DVGW-Technologiezentrum Wasser. 1996. *Internal Corrosion of Water Distribution Systems.* 2nd edition. AwwaRF Report 90508. Project #725. Denver: AwwaRF.
- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. *Optimizing Corrosion Control in Distribution Systems.* AwwaRF Report 90983. Project #2648. Denver: AwwaRF.
- Smith, C.D. (editor). 2005. *Water Distribution System Assessment Workbook*. 85 pp. Denver: AWWA.

Taste and color problems

Description

Aluminum can be found in source water or introduced through coagulant use or as an impurity in lime. Aluminum is more soluble at high pH. Since enhanced softening is conducted at high pH, it allows more aluminum to pass through the treatment plant. In waters with high magnesium, enhanced softening can form lighter floc, which may not settle as well. This can also allow higher levels of aluminum to enter the distribution system. When aluminum precipitates out in the distribution system it can cause colored water and taste complaints.

Further Reading

- AWWA. 2003a. *Principles and Practices of Water Supply Operations: Water Transmission and Distribution*. 3rd Edition. 553 pp. Denver: AWWA.
- Von Huben, H. 1999. *Water Distribution Operator Training Handbook.* 2nd Edition. 278 pp. Denver: AWWA.
- Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality.* AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
- Lauer, W.C. 2005. *Water Quality in the Distribution System*. Denver: AWWA.
- Mays, L.W. 1999. *Water Distribution Systems Handbook*. 900 pp. Denver: AWWA.

Change in finished water NOM

Description

Enhanced softening preferentially removes high molecular weight organic molecules and organic molecules with oxygen-containing functional groups. NOM removal through enhanced softening varies widely depending on the nature and concentration of the NOM, water quality characteristics such as hardness, other plant treatment processes, and type and dose of the softening chemical. Some NOM in the finished water can help inhibit corrosion.

Further Reading

- AWWA. 1990. *Water Quality and Treatment*. F.W. Pontius (editor). New York : McGraw-Hill.
- AWWA. 2003a. *Principles and Practices of Water Supply Operations: Water Transmission and Distribution*. 3rd Edition. 553 pp. Denver: AWWA.
- Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality.* AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
- Lauer, W.C. 2005. *Water Quality in the Distribution System*. Denver: AWWA.

High iron

Description

In enhanced softening, the pH of the water is typically raised to a value above 10. However, most other water treatment processes are operated at much lower pHs. Therefore, when discontinuing softening, systems can expect to have a much lower finished water pH. As the pH decreases, systems can expect an increase in corrosion of distribution system pipes, resulting in increased concentrations of metals such as iron, copper, and lead in the water.

Further Reading

- AwwaRF and DVGW-Technologiezentrum Wasser. 1996. *Internal Corrosion of Water Distribution Systems.* 2nd edition. AwwaRF Report 90508. Project #725. Denver: AwwaRF.
- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. *Optimizing Corrosion Control in Distribution Systems*. AwwaRF Report 90983. Project #2648. Denver: AwwaRF.

Change in DBP concentration/composition

Description

Softening removes DBP precursors, reducing the formation of DBPs. Therefore, by installing softening, systems can decrease TTHM and HAA5 levels in the plant and the distribution system. Systems installing softening will also see a shift in the balance of DBPs in the distribution system because TTHM formation is favored over HAA5 formation at the high pH levels used in softening. In addition, prechlorination with softening can reduce the amount of DBP precursor removal (AWWA 1990) and should be avoided if possible.

Further Reading

- AWWA. 1990. *Water Quality and Treatment*. F.W. Pontius (editor). New York: McGraw-Hill.
- Von Huben, H. 1999. *Water Distribution Operator Training Handbook.* 2nd Edition. 278 pp. Denver: AWWA.
- Smith, C.D. (editor). 2005. *Water Distribution System Assessment Workbook*. 85 pp. Denver: AWWA.

Pinhole leaks
Description Adding softening raises pH and alkalinity of the finished water. Discontinuing softening lowers the pH and alkalinity. Lower pH can be corrosive to copper, but high pH in the absence of inhibitors such as NOM has also been shown to initiate pitting corrosion in copper.
Further Reading • Edwards, M., J.C. Rushing, S. Kvech, and S. Reiber. 2004. Assessing copper pinhole leaks in residential plumbing. *Water Science and Technology*. 49(2): 83-90. • Edwards, M., J.F. Ferguson, S. Reiber. 1994. The Pitting Corrosion of Copper. *Journal of American Water Works Association*. 86(7): 74-91. • AwwaRF and DVGW-Technologiezentrum Wasser. 1996. *Internal Corrosion of Water Distribution Systems.* 2nd edition. AwwaRF Report 90508. Project #725. Denver: AwwaRF.

ADDING OZONE

The following impacts to your distribution system may result from adding ozone:

- Increased lead and copper in tap water
- Taste and odor
- Change in finished water NOM
- Colored water
- High iron
- Change in DBP concentration/composition

The following references can provide further information about how to address most of these impacts. Additional references and brief descriptions are listed by impact in the table below.

- USEPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014.
- USEPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual. EPA 815-R-99-011. August 1999.

Refer to Section 5.2 for additional information on adding ozone.

Increased lead and copper in tap water
Description When ozone reacts in water it produces dissolved oxygen. Dissolved oxygen can cause increased growth of aerobic bacteria, which can lead to microbial-induced corrosion in the distribution system. Dissolved oxygen is also corrosive, and if not removed, it can directly cause lead and copper corrosion in the distribution system. Ozonation also breaks down organics into smaller molecules that are more readily used as a food source by microorganisms. If not removed, this can lead to increased microbial growth and microbial-induced corrosion in the distribution system.
Further Reading • White, G.C. 1999. *Handbook of Chlorination and Alternative Disinfectants*. 4th Edition. New York: Van Nostrand Reinhold Co. • Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. *Optimizing Corrosion Control in Distribution Systems*. AwwaRF Report 90983. Project #2648. Denver: AwwaRF.

Taste and odor

Description

Ozonation reacts with organics to break them down into smaller molecules, such as aldehydes and ketones. Aldehydes can impart tastes and odors to water. In addition, ozone itself can impart an “ozonous” or “oxidant” taste to the water even in the absence of a residual (AwwaRF and Lyonnaise des Eaux 1995).

Further Reading

- AwwaRF and Lyonnaise des Eaux. 1995. *Advances in Taste and Odor Treatment and Control*. AwwaRF Report 90610. Project #629. Denver: AwwaRF.
- Singer, P.C. (editor). 1999. *Formation and Control of Disinfection By-Products in Drinking Water*. 424 pp. Denver: AWWA.
- AWWA. 2003a. *Principles and Practices of Water Supply Operations: Water Transmission and Distribution*. 3rd Edition. 553 pp. Denver: AWWA.
- Von Huben, H. 1999. *Water Distribution Operator Training Handbook*. 2nd Edition. 278 pp. Denver: AWWA.
- Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality*. AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
- Lauer, W.C. 2005. *Water Quality in the Distribution System*. Denver: AWWA.
- Mays, L.W. 1999. *Water Distribution Systems Handbook*. 900 pp. Denver: AWWA.

Change in finished water NOM

Description

Ozone reacts with NOM in water to destroys many DBP precursors. However, ozone breaks the NOM down into smaller organic molecules that are readily used as a food source by microorganisms, referred to as AOC. If ozone is followed by biological filtration, the AOC concentration can also be significantly reduced.

Further Reading

- Singer, P.C. (editor). 1999. *Formation and Control of Disinfection By-Products in Drinking Water*. 424 pp. Denver: AWWA.
- Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality*. AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
- Lauer, W.C. 2005. *Water Quality in the Distribution System*. Denver: AWWA.

Colored water

Description

Ozonation produces dissolved oxygen in water, which is corrosive. In addition, dissolved oxygen can cause increased microbial activity in the distribution system and microbial-induced corrosion. If iron pipe is present in the distribution system, increased corrosion can lead to colored water problems.

Further Reading

- White, G.C. 1999. *Handbook of Chlorination and Alternative Disinfectants*. 4th Edition. New York: Van Nostrand Reinhold Co.
- Von Huben, H. 1999. *Water Distribution Operator Training Handbook*. 2nd Edition. 278 pp. Denver: AWWA.
- AWWA. 2003a. *Principles and Practices of Water Supply Operations: Water Transmission and Distribution*. 3rd Edition. 553 pp. Denver: AWWA.
- Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality*. AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
- Mays, L.W. 1999. *Water Distribution Systems Handbook*. 900 pp. Denver: AWWA.

High iron

Description

Ozonation produces dissolved oxygen in water, which is corrosive. In addition, dissolved oxygen can cause increased microbial activity in the distribution system and microbial-induced corrosion. If iron pipe is present in the distribution system, increased corrosion can lead to higher iron levels in the water.

Further Reading

- USEPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014.
- USEPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual. EPA 815-R-99-011. August 1999.
- White, G.C. 1999. *Handbook of Chlorination and Alternative Disinfectants*. 4th Edition. New York: Van Nostrand Reinhold Co.
- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. *Optimizing Corrosion Control in Distribution Systems*. AwwaRF Report 90983. Project #2648. Denver: AwwaRF.

Change in DBP concentration/composition

Description

Ozone does not form chlorinated DBPs. Therefore, switching from chlorine or chlorine dioxide as a primary disinfectant to ozone will result in significantly lower levels of TTHM and HAA5. However, ozone reacts with bromide to form bromate, which is a regulated DBP.

Further Reading

- Von Huben, H. 1999. *Water Distribution Operator Training Handbook*. 2nd Edition. 278 pp. Denver: AWWA.
- Smith, C.D. (editor). 2005. *Water Distribution System Assessment Workbook*. 85 pp. Denver: AWWA.

ADDING CHLORINE DIOXIDE

The following impacts to your distribution system may result from adding chlorine dioxide:

- Increased lead and copper in tap water
- Taste and odor
- Change in finished water NOM
- Colored water
- High iron
- Change in DBP concentration/composition

References, along with brief descriptions, that are specific to individual issues are listed by impact in the table below. Refer to Sections 5.4 and 5.5 for additional information on adding chlorine dioxide.

Increased lead and copper in tap water
<u>Description</u> Changing to chlorine dioxide from another oxidant can change the ORP of the tap water. Changes in ORP can alter the nature of passivating layers and could result in the release of lead and other metals into the distribution system. It is also possible that AOC formed by chlorine dioxide could encourage microbial-induced corrosion.
<u>Further Reading</u> • AWWA. 2005a. *Managing Change and Unintended Consequences: Lead and Copper Rule Corrosion Control Treatment.* Denver: AwwaRF. • AwwaRF and DVGW-Technologiezentrum Wasser. 1996. *Internal Corrosion of Water Distribution Systems.* 2nd edition. AwwaRF Report 90508. Project #725. Denver: AwwaRF. • Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. *Optimizing Corrosion Control in Distribution Systems.* AwwaRF Report 90983. Project #2648. Denver: AwwaRF
Taste and odor
<u>Description</u> Chlorine dioxide has a strong chlorinous odor. Even when chlorine dioxide is used only as a primary disinfectant, customers may still detect a strong chlorinous odor at the tap as chlorite can combine with free chlorine in the distribution system to form chlorine dioxide. If a customer has recently installed new carpeting, airborne organic compounds from the carpeting can react with the chlorine dioxide emanating from the customer's tap to form offensive odors. These odors have been described as "cat-urine-like" and "kerosene-like" (Hoehn et al. 1990).

Further Reading

- AWWA. 2003a. *Principles and Practices of Water Supply Operations: Water Transmission and Distribution*. 3rd Edition. 553 pp. Denver: AWWA
- Von Huben, H. 1999. *Water Distribution Operator Training Handbook*. 2nd Edition. 278 pp. Denver: AWWA.
- Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality.* AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
- Lauer, W.C. 2005. *Water Quality in the Distribution System*. Denver: AWWA.
- Mays, L.W. 1999. *Water Distribution Systems Handbook*. 900 pp. Denver: AWWA.

Change in finished water NOM

Description

Chlorine dioxide reacts with organic matter in water. These reactions can form smaller organic molecules or AOC. Although AOC production is not as much of an issue with chlorine dioxide as it is with ozone, it is still possible AOC could increase and in turn increase microbial growth.

Further Reading

- USEPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014.
- Andrews, R.C., Z. Alam, R. Hofmann, L. Lachuta, R. Cantwell, S. Andrews, E. Moffet, G.A. Ganon, J. Rand, and C. Chauret. 2005. *Impact of Chlorine Dioxide on Transmission, Treatment, and Distribution System Performance*. AwwaRF Report 91082. Project #2843. Denver: AwwaRF.
- AWWA. 2003a. *Principles and Practices of Water Supply Operations: Water Transmission and Distribution*. 3rd Edition. 553 pp. Denver: AWWA.
- Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality.* AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
- Lauer, W.C. 2005. *Water Quality in the Distribution System*. Denver: AWWA.

Colored water

Description

Chlorine dioxide can react with organic chemicals to form AOC. AOC can act as a food source for microbes, which can in turn increase the corrosion rate causing corrosion products to be released into the distribution system. The change in ORP can also destabilize some already formed layers of corrosion products, leading to colored water.

Further Reading

- USEPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014.
- Andrews, R.C., Z. Alam, R. Hofmann, L. Lachuta, R. Cantwell, S. Andrews, E. Moffet, G.A. Ganon, J. Rand, and C. Chauret. 2005. *Impact of Chlorine Dioxide on Transmission, Treatment, and Distribution System Performance*. AwwaRF Report 91082. Project #2843. Denver: AwwaRF.
- Von Huben, H. 1999. *Water Distribution Operator Training Handbook*. 2nd Edition. 278 pp. Denver: AWWA.
- AWWA. 2003a. *Principles and Practices of Water Supply Operations: Water Transmission and Distribution*. 3rd Edition. 553 pp. Denver: AWWA.
- Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality*. AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
- Mays, L.W. 1999. *Water Distribution Systems Handbook*. 900 pp. Denver: AWWA.

High iron

Description

Chlorine dioxide can react with organic matter to form AOC which can cause microbial-induced corrosion. Changes in water ORP resulting from chlorine dioxide use may also allow dissolution of existing scales.

Further Reading

- USEPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014.
- Andrews, R.C., Z. Alam, R. Hofmann, L. Lachuta, R. Cantwell, S. Andrews, E. Moffet, G.A. Ganon, J. Rand, and C. Chauret. 2005. *Impact of Chlorine Dioxide on Transmission, Treatment, and Distribution System Performance*. AwwaRF Report 91082. Project #2843. Denver: AwwaRF.
- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. *Optimizing Corrosion Control in Distribution Systems*. AwwaRF Report 90983. Project #2648. Denver: AwwaRF.

Change in DBP concentration/composition

Description

Chlorine dioxide does not form significant amounts of TTHM or HAA5. Therefore, switching from chlorine or chloramines to chlorine dioxide will result in lower levels of these DBPs. However, chlorine dioxide generators produce some chlorine as a byproduct so some TTHM and HAA5 will be formed. In addition, chlorine dioxide can oxidize bromide ions to bromine, which can then react with organic matter in the water to produce brominated DBPs. Chlorine dioxide also reacts with NOM to produce chlorite, which is a regulated DBP.

Further Reading

- USEPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014.
- White, G.C. 1999. *Handbook of Chlorination and Alternative Disinfectants*. 4th Edition. New York: Van Nostrand Reinhold Co.
- Gates, D. 1997. *The Chlorine Dioxide Handbook*. 177pp. Denver: AWWA.
- Smith, C.D. (editor). 2005. *Water Distribution System Assessment Workbook*. 85 pp. Denver: AWWA.
- Von Huben, H. 1999. *Water Distribution Operator Training Handbook*. 2nd Edition. 278 pp. Denver: AWWA.

ENHANCED COAGULATION

The following impacts to your distribution system may result from using enhanced coagulation:

- Reduction in finished water pH
- Increased lead and copper in tap water
- Change/disruption of scale
- Change in finished water NOM
- Change in DBP concentration/composition
- Change in chloride:sulfate ratio

The following references can provide further information about how to address most of these impacts. Additional references and brief descriptions are listed by impact in the table below.

- USEPA. 1999h. Enhanced Coagulation and Enhanced Precipitative Softening Guidance Manual. Office of Water. EPA 815-R-99-012.
- USEPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual. EPA 815-R-99-011. August 1999.

Refer to Section 3.7 for additional information on using enhanced coagulation.

Change in finished water pH
<u>Description</u> Enhanced coagulation tends to reduce the pH of the water. This can be accomplished by adding chemicals specifically to reduce the pH to as low as 5.5 or as a consequence of using heavy alum or ferric coagulant doses.
<u>Further Reading</u> • Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality.* AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA. • Mays, L.W. 1999. *Water Distribution Systems Handbook*. 900pp. Denver: AWWA.
Increased lead and copper in tap water
<u>Description</u> Enhanced coagulation tends to reduce the pH of the water. This can be accomplished by adding chemicals specifically to reduce the pH to as low as 5.5 or as a consequence of using heavy alum or ferric coagulant doses. In addition, switching coagulants for enhanced coagulation can lead to reduced pH. A reduction in pH can cause increased lead and copper corrosion.
<u>Further Reading</u> • Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. *Optimizing Corrosion Control in Distribution Systems*. AwwaRF Report 90983. Project #2648. Denver: AwwaRF.

Change/disruption of scale

Description

Enhanced coagulation tends to reduce the pH of the water. This can be accomplished by adding chemicals specifically to reduce the pH to as low as 5.5 or as a consequence of using heavy alum or ferric coagulant doses. A lower pH can cause disruption or dislodgement of scales formed from corrosion byproducts or protective scales, such as calcium carbonate.

Further Reading

- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. *Optimizing Corrosion Control in Distribution Systems*. AwwaRF Report 90983. Project #2648. Denver: AwwaRF.
- Smith, C.D. (editor). 2005. *Water Distribution System Assessment Workbook*. 85 pp. Denver: AWWA.

Change in finished water NOM

Description

Enhanced coagulation increases the removal of TOC, which is a surrogate measure of NOM. Therefore, the NOM entering the distribution system is significantly reduced. Some NOM in finished water can help inhibit corrosion.

Further Reading

- Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality.* AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
- Lauer, W.C. 2005. *Water Quality in the Distribution System*. Denver: AWWA.

Change in DBP concentration/composition

Description

Enhanced coagulation improves the removal of DBP precursors in a conventional water treatment plant, reducing the formation of DBPs. Therefore, by practicing enhanced coagulation, systems can decrease TTHM and HAA5 levels in the plant and the distribution system.

Further Reading

- Von Huben, H. 1999. *Water Distribution Operator Training Handbook*. 2nd Edition. 278 pp. Denver: AWWA.
- Smith, C.D. (editor). 2005. *Water Distribution System Assessment Workbook*. 85 pp. Denver: AWWA.

Change in chloride:sulfate ratio

Description

One option for systems initiating enhanced coagulation is to switch coagulants to increase TOC removal. Some coagulants, such as aluminum sulfate (alum) and ferric sulfate add sulfate to the water. Other coagulants, such as ferric chloride add chloride to the water. Therefore, switching to or from any of these coagulants can affect the chloride to sulfate ratio and, as a result, may cause increased lead and copper corrosion.

Further Reading

- Lauer, W.C. 2005. *Water Quality in the Distribution System*. Denver: AWWA.

INSTALLING NANOFILTRATION

The following impacts to your distribution system may result from installing nanofiltration:

- Change in finished water pH
- Increased lead and copper in tap water
- Change/disruption of scale
- Change in finished water NOM
- Colored water
- High iron
- Change in DBP concentration/composition
- Pinhole leaks

The following reference can provide further information about how to address most of these impacts. Additional references and brief descriptions are listed by impact in the table below.

- AWWA. 1999. *Reverse Osmosis and Nanofiltration*. AWWA Manual M46.

Refer to Section 4.3 for additional information on installing nanofiltration.

Change in finished water pH
Description Nanofiltration can remove virtually all particulate matter as well as larger dissolved compounds. However, it cannot remove dissolved gasses. Therefore, carbon dioxide in the feed water is not removed, while alkalinity, hardness, and other dissolved compounds are removed. Therefore, the carbonate system must re-equilibrate, resulting in the production of the hydrogen ion and loss of alkalinity. This in turn results in a lowering of the pH of the water.
Further Reading • Schippers, J.C., J.C. Kruithof, M.M. Nederlof, J.A.M.H. Hofman, and J. Taylor. 2004. *Integrated Membrane Systems*. AwwaRF Report 90899. Project #264. Denver: AwwaRF. • Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality.* AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA. • Mays, L.W. 1999. *Water Distribution Systems Handbook*. 900 pp. Denver: AWWA.
Increased lead and copper in tap water
Description Nanofiltration can also result in a lowering of the pH of the water. The lower pH water will be more corrosive to lead and copper piping in the distribution system. As a result, both increased lead and copper levels can occur.

Further Reading

- AwwaRF and DVGW-Technologiezentrum Wasser. 1996. *Internal Corrosion of Water Distribution Systems.* 2nd edition. AwwaRF Report 90508. Project #725. Denver: AwwaRF.
- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. *Optimizing Corrosion Control in Distribution Systems*. AwwaRF Report 90983. Project #2648. Denver: AwwaRF.

Change/disruption of scale

Description

Nanofiltration can also result in a lowering of the pH of the water. A lower pH can cause disruption or dislodgement of scales formed from corrosion byproducts or protective scales, such as calcium carbonate.

Further Reading

- AwwaRF and DVGW-Technologiezentrum Wasser. 1996. *Internal Corrosion of Water Distribution Systems.* 2nd Edition. AwwaRF Report 90508. Project #725. Denver: AwwaRF.
- Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. *Optimizing Corrosion Control in Distribution Systems*. AwwaRF Report 90983. Project #2648. Denver: AwwaRF.
- Smith, C.D. (editor). 2005. *Water Distribution System Assessment Workbook*. 85 pp. Denver: AWWA.

Change in finished water NOM

Description

Nanofiltration is a physical process that removes molecules from water. Nanofiltration can remove both particulate matter and dissolved compounds, including NOM. Thus, the NOM concentration entering the distribution system is significantly reduced. Some NOM in finished water can help inhibit corrosion.

Further Reading

- AWWA. 2003a. *Principles and Practices of Water Supply Operations: Water Transmission and Distribution*. 3rd Edition. 553 pp. Denver: AWWA.
- Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality.* AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
- Lauer, W.C. 2005. *Water Quality in the Distribution System*. Denver: AWWA.

Colored water

Description

Nanofiltration can also result in a lowering of the pH of the water. The lower pH water will be more corrosive to iron pipe in the distribution system. The corrosion will result in increased iron in the water, which can lead to colored water problems.

<table>
<tr><td>Further Reading
• AwwaRF and DVGW-Technologiezentrum Wasser. 1996. <i>Internal Corrosion of Water Distribution Systems</i>. 2nd edition. AwwaRF Report 90508. Project #725. Denver: AwwaRF.
• Von Huben, H. 1999. <i>Water Distribution Operator Training Handbook</i>. 2nd Edition. 278 pp. Denver: AWWA.
• AWWA. 2003a. <i>Principles and Practices of Water Supply Operations: Water Transmission and Distribution</i>. 3rd Edition. 553 pp. Denver: AWWA.
• Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. <i>Guidance Manual for Maintaining Distribution System Water Quality</i>. AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
• Mays, L.W. 1999. <i>Water Distribution Systems Handbook</i>. 900pp. Denver: AWWA.</td></tr>
<tr><td>High iron</td></tr>
<tr><td>Description
Nanofiltration can also result in a lowering of the pH of the water. The lower pH water will be more corrosive to iron pipe in the distribution system. Corrosion of iron pipe will result in increased iron in the water.</td></tr>
<tr><td>Further Reading
• AwwaRF and DVGW-Technologiezentrum Wasser. 1996. <i>Internal Corrosion of Water Distribution Systems</i>. 2nd edition. AwwaRF Report 90508. Project #725. Denver: AwwaRF.
• Duranceau, S.J., D. Townley, and G.E.C. Bell. 2004. <i>Optimizing Corrosion Control in Distribution Systems</i>. AwwaRF Report 90983. Project #2648. Denver: AwwaRF.</td></tr>
<tr><td>Change in DBP concentration/composition</td></tr>
<tr><td>Description
Nanofiltration physically removes DBP precursors, reducing the formation of DBPs. Therefore, by installing nanofiltration, systems can decrease TTHM and HAA5 levels in the plant and the distribution system.</td></tr>
<tr><td>Further Reading
• Von Huben, H. 1999. <i>Water Distribution Operator Training Handbook</i>. 2nd Edition. 278 pp. Denver: AWWA.
• Smith, C.D. (editor). 2005. <i>Water Distribution System Assessment Workbook</i>. 85 pp. Denver: AWWA.</td></tr>
<tr><td>Pinhole leaks</td></tr>
<tr><td>Description
Nanofiltration can remove most larger particles and many smaller ones. This includes NOM, which has been shown to inhibit pitting corrosion in copper piping.</td></tr>
<tr><td>Further Reading
• Edwards, M., J.C. Rushing, S. Kvech, and S. Reiber. 2004. Assessing copper pinhole leaks in residential plumbing. <i>Water Science and Technology</i>. 49(2): 83-90.
• Edwards, M., J.F. Ferguson, S. Reiber. 1994. The Pitting Corrosion of Copper. <i>Journal of American Water Works Association.</i> 86(7): 74-91.
• AwwaRF and DVGW-Technologiezentrum Wasser. 1996. <i>Internal Corrosion of Water Distribution Systems.</i> 2nd edition. AwwaRF Report 90508. Project #725. Denver: AwwaRF.</td></tr>
</table>

INSTALLING GRANULAR ACTIVATED CARBON

The following impacts to your distribution system may result from installing granulated activated carbon (GAC):

- Increased coliform and heterotrophic bacteria

The following references can provide further information about how to address this impact. A brief description of the distribution system impact is provided in the table below.

- AWWA. 1990. *Water Quality and Treatment*. F.W. Pontius (editor). New York: McGraw-Hill.
- American Chemical Society. 1983. *Treatment of Water by Granular Activated Carbon*. M.J. McGuire and I.H. Suffet (editors). Washington, D.C.: American Chemical Society.
- Von Huben, H. 1999. *Water Distribution Operator Training Handbook*. 2nd Edition. 278 pp. Denver: AWWA.
- AWWA. 2003a. *Principles and Practices of Water Supply Operations: Water Transmission and Distribution*. 3rd Edition. 553 pp. Denver: AWWA.
- Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality*. AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
- Lauer, W.C. 2005. *Water Quality in the Distribution System*. Denver: AWWA.
- Mays, L.W. 1999. *Water Distribution Systems Handbook*. 990 pp. Denver: AWWA.
- Smith, C.D. (editor). 2005. *Water Distribution System Assessment Workbook*. 85 pp. Denver: AWWA.

Refer to Section 4.1 for additional information on installing GAC.

Increased coliform and heterotrophic bacteria
Description Heterotrophic bacteria can colonize GAC filters and can be shed in the filter effluent. The number of bacteria in the effluent of GAC systems is frequently higher than influent levels. This problem is compounded when GAC filters are operated in biologically active mode, where biological growth on the GAC filters is promoted.

INSTALLING OZONE WITHOUT SUBSEQUENT BIOLOGICAL FILTRATION

The following impact to your distribution system may result from installing ozone without subsequent biological filtration:

- Increased coliform and heterotrophic bacteria

The following references can provide information about how to address this impact. A brief description of the distribution system impact is provided in the table below.

- Singer, P.C. (editor). 1999. *Formation and Control of Disinfection By-Products in Drinking Water*. 424 pp. Denver: AWWA.
- USEPA. 1999b. Alternative Disinfectants and Oxidants Guidance Manual. EPA 815-R-99-014.
- USEPA. 1999f. Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual. EPA 815-R-99-011. August 1999.
- Von Huben, H. 1999. *Water Distribution Operator Training Handbook*. 2nd Edition. 278 pp. Denver: AWWA.
- AWWA. 2003a. *Principles and Practices of Water Supply Operations: Water Transmission and Distribution*. 3rd Edition. 553 pp. Denver: AWWA.
- Kirmeyer, G.J., M. Friedman, J. Clement, A. Sandvig, P.F. Noran, K.D. Martel, D. Smith, M. LeChevallier, C. Volk, E. Antoun, D. Hiltebrand, J. Dykesan, and R. Cushing. 2000b. *Guidance Manual for Maintaining Distribution System Water Quality*. AwwaRF Report 90798. Project #357. Denver: AwwaRF and AWWA.
- Lauer, W.C. 2005. *Water Quality in the Distribution System*. Denver: AWWA.
- Mays, L.W. 1999. *Water Distribution Systems Handbook*. 990pp. Denver: AWWA.
- Smith, C.D. (editor). 2005. *Water Distribution System Assessment Workbook*. 85 pp. Denver: AWWA.

Refer to Section 5.2 for additional information on installing ozone without subsequent biological filtration.

Increased coliform and heterotrophic bacteria
Description Ozone reacts with NOM in water to destroys many DBP precursors. However, ozone breaks the NOM down into smaller organic molecules that are readily used as a food source by microorganisms, referred to as assimilable organic carbon (AOC). If ozone is followed by biological filtration, the AOC concentration can be significantly reduced. However, if ozone is not followed by biological filtration, the AOC will pass into the distribution system where it can be readily used by microorganisms. This will result in increased heterotrophic bacterial growth and possibly higher coliform numbers and may cause nitrification in chloraminated systems.

Appendix D

Tools for Evaluating Impacts of Treatment Changes on Lead and Copper Rule Compliance

Appendix D
Tools for Evaluating Impacts of Treatment Changes on Lead and Copper Rule Compliance

Currently, water systems work with their primacy agencies (primarily state regulatory agencies) to ensure compliance with the LCR. The state establishes optimal water quality parameters that the system must monitor, in addition to regulatory lead and copper tap sampling, to evaluate compliance with the Rule. The system must maintain these water quality parameters at specified levels and/or ranges to maintain optimal corrosion control treatment (OCCT). Water systems must notify their primacy agency no later than 60 days after the addition of a new source or implementation of a treatment or source water change; however, systems are *encouraged* to provide notification to the State prior to any treatment change to minimize risks that the change will adversely impact OCCT (40 CFR 141.8(b)(3)). Proposed revisions to the LCR would *require* water systems to provide advanced notification to their primacy agency and to get approval for intended changes in treatment or the addition of a new source that could increase release and uptake of lead. This proposed revision would allow states and water systems to take as much time as needed to consult about potential problems, allowing evaluations to be completed that would strive to avoid or minimize potential problems with corrosion control and ultimately ensure that OCCT is being maintained after the treatment change has been made. Conducting evaluations of the potential impact that a proposed treatment change may have on LCR compliance can provide information both parties can utilize in discussions of how best to maintain OCCT in the system. This appendix provides a summary of various corrosion assessment tools that can be used in these evaluations.

Corrosion assessment tools should be used prior to a treatment change to predict the potential for causing metals release and uptake associated with the change. In cases where metals release has already become a problem, these assessment tools can also be used to determine where and why metals release is occurring and to test alternative corrosion control strategies.

There are many types of corrosion assessment tools ranging from relatively inexpensive data analyses to extensive pilot and partial system studies. For the purposes of this appendix, corrosion assessment tools have been organized into the following categories:

- Desktop studies
- Water Quality Monitoring
  - Expanded baseline monitoring
  - Supplemental tap water quality monitoring
- Blending analysis
- Solubility models
- Laboratory and Field Testing
  - Treatment simulation
  - Pipe loop testing
  - Coupon studies
  - Electrochemical measurement techniques

  - Scale and solids analysis
  - Partial system testing

These tools can be used in a progressive manner to evaluate potential impacts of lead release and uptake by the water associated with a change in treatment or operations. For example, a desktop study, which is based on review and evaluation of readily available data and information, may be sufficient to understand the potential for metals release. However, in some cases there may be system-specific conditions (e.g., unlined cast iron pipe, changes in secondary disinfectant) that warrant additional study. In such cases, diagnostic tools such as pipe loop studies or scale analysis could be used to help establish optimum water quality and treatment conditions. In cases where the cause(s) of increased lead and/or copper release is not known, other diagnostic tools such as supplemental tap water quality monitoring could be useful. Ultimately, the system should select the appropriate corrosion assessment tool(s) for their applications.

Exhibit D.1 provides a summary of the assessment tools, their usefulness in terms of assessing lead and copper release, and their relative costs. The sections that follow describe each tool and identify their uses and limitations. A list of references where the reader can find additional information is presented at the end of each section and in Chapter 7 of this guidance document.

Exhibit D.1 Summary of Corrosion Assessment Tools

Tool	Section	Description	Potential Uses*	Relative Cost
Desktop studies	D.1	Review of current and historical information such as literature, data, expert opinion, and analogous system experiences	1, 2	Low
Expanded baseline monitoring	D.2.1	Increased monitoring in the distribution system for optimal water quality parameters (pH, alkalinity, calcium, conductivity, temperature, and corrosion inhibitors) and other parameters (e.g., ORP) that may provide useful information on metals release potential.	1, 2, 3	Medium
Supplemental tap water quality monitoring	D.2.2	Includes LCR compliance sampling at more sites and/or more frequently and water line profiling at select sites	1, 2, 3	Medium - High
Blending analysis	D.3	Predicting the water quality of multiple sources blended in a distribution system	1, 2, 3	Low
Solubility models	D.4	Using models to predict the thermodynamic stability of a metal under specific water quality conditions and evaluate the mechanisms underlying scale development and passivation.	1, 2, 3	Low
Treatment Simulation	D.5.1	Using models or conducting jar tests to simulate the effects of treatment changes	1	High
Pipe Loop Studies	D.5.2	Studies that measure metals release under different water quality conditions.	1, 3	High
Coupon Studies	D.5.3	Studies that utilize metal coupons to determine metal loss and corrosion rates in a given water quality.	1, 3	High
Electrochemical Measurement Techniques	D.5.4	Using instruments to measure the potential or the current on the metal surface and determine the corrosion rate	1, 3	High
Scale and Solids Analysis	D.5.5	Analytical methods used to examine the accumulated corrosion products on pipes.	1, 2, 3	High
Partial System Testing	D.5.6	Testing a corrosion treatment method on a portion of the distribution system which has been hydraulically isolated from the rest of the system	3	High

*
1 = To predict the impact of a change in treatment or operations on metals release
2 = To diagnose the cause and location of metals release
3 = To test the effectiveness of corrosion control alternatives

D.1 Desktop Studies

Description of Method

Desktop studies utilize current and historical information to document the extent, magnitude, and possible causes of potential problems. By referencing a variety of information sources, desktop studies can be used to 1) develop and assess treatment options and the corresponding water quality changes that potentially can occur, 2) identify the secondary impacts of those treatment and water quality changes, and 3) identify actions that will help to mitigate those potential problems. Information sources for desktop studies can include the following:

- Literature reviews;
- Reviews of historical water quality, treatment, and modeling data;
- Review of standards and guidance documents;
- Expert opinions; and
- Consultation with, and analyses of data from other systems with similar water quality and distribution systems (analogous systems).

Literature reviews of field and laboratory studies may help reveal corrosion mechanisms and inter-relationships between lead and copper leaching and water quality conditions in the system, and also identify possible corrosion prevention strategies. The AWWA Research Foundation (AwwaRF) has published an overview of corrosion research (AwwaRF, 2007) and EPA includes references to several historical corrosion studies in drinking water regulations and guidance manuals. As part of a recent study, the American Water Works Association (AWWA, 2005b) summarized unintended consequences associated with changes in source water, treatment, and operations and maintenance (O&M) practices on lead and copper release and uptake in the distribution system. These unintended consequences include changes in corrosion-related water quality parameters, changes to existing scales, and other corrosion-related impacts. The study includes a checklist which can serve as a screening tool in identifying possible effects of changes on LCR compliance.

Historical data collected by utilities, including treatment data, finished and distribution system water quality and materials evaluations, existing LCR monitoring data, modeling results, and results from special studies, can all be utilized in a desktop evaluation to identify potential simultaneous compliance issues. Burlingame and Sandvig (2004) provide an example of how one system evaluated historical lead and copper data to determine if changes in operations, treatment, or source were impacting lead and copper levels.

Desktop studies can also incorporate a thorough review of regulatory standards and associated guidance documents. The EPA has developed a guidance manual for selecting lead and copper corrosion control strategies which incorporates information on secondary impacts of various corrosion treatment approaches (USEPA 2003h).

Review of case studies of systems with similar water quality and treatment scenarios can provide insight into potential problems associated with implementation of corrosion control treatment and the ability to maintain compliance with regulations. Appendix B of this guidance manual provides numerous case studies showing how different water systems have addressed simultaneous compliance and operational issues. AWWA's Water Industry Technical Action Fund collected lead and copper data along with other water quality data such as, alkalinity, calcium, and the type of corrosion inhibitor used for 400 US water systems (AWWA, 1993). Systems could use this data to evaluate the effectiveness of corrosion inhibitors for systems with similar water quality.

Uses and Limitations

Desktop studies can be used by systems to characterize the potential for corrosion problems to occur when contemplating changes in water quality and/or treatment. Desktop studies are also a relatively inexpensive method for screening a number of potential solutions to a corrosion problem. Desktop studies provide a way for systems to learn from the experience of others and focus efforts on the most effective techniques.

In many cases, results from desktop studies can be sufficient for understanding potential compliance concerns associated with a change in treatment or operations. Desktop studies may be limited however, in situations where supply, treatment, and distribution system configurations and operations are complex and/or unusual. In these situations, desktop studies could be used in combination with other corrosion assessment tools. When evaluating corrosion control treatment options, systems should consider using desktop studies in combination with other tools to identify any system-specific treatment issues.

References

AwwaRF and DVGW-Technologiezentrum Wasser. 1996. *Internal Corrosion of Water Distribution Systems*. 2nd edition. AwwaRF Report 90508. Project #725. Denver: AwwaRF.

AWWA. 1993. *Initial Monitoring Experiences of Large Water Utilities Under EPA's Lead and Copper Rule.* Denver: WITAF.

AWWA. 2005a. *Managing Change and Unintended Consequences: Lead and Copper Rule Corrosion Control Treatment*. Denver: AWWA.

AwwaRF. 2007. *Distribution System Corrosion and the Lead and Copper: An Overview of AwwaRF Research*. AwwaRF Special Report. Denver: AwwaRF.

Burlingame, G.A. and A. Sandvig. 2004. How to Mine Your Lead and Copper Data. *Opflow*. 30(6):16-19.

Economic and Engineering Services, Inc. and Illinois State Water Survey. 1990. *Lead Control Strategies.* Denver: AwwaRF and AWWA.

Hecht, P.M., and E.A. Turner. 2004. Washington Aqueduct Desktop & Flow-Through Study. Presented at *Getting the Lead Out: Analysis & Treatment of Elevated Lead Levels in DC's Drinking Water at the 2004 AWWA WQTC.*

USEPA. 2003h. Revised Guidance Manual for Selecting Lead and Copper Control Strategies. Office of Water. EPA 816-R-03-001. March, 2003.

D.2 Water Quality Monitoring

This section describes two types of water quality monitoring tools, expanded baseline monitoring of the distribution system and supplemental monitoring of corrosion products at the tap.

D.2.1 Expanded Baseline Monitoring

Description of Method

The LCR requires systems to monitor basic water quality parameters in the distribution system. Depending on the corrosion control treatment, some combination of the following parameters is typically required: pH, alkalinity, calcium, conductivity, temperature, and the corrosion inhibitor concentration. Results from this and other monitoring programs can provide useful information on the state of corrosion within the distribution system. For example, bacteriological data from compliance monitoring for the Total Coliform Rule (TCR) can help systems identify areas likely to suffer from microbial induced corrosion. Sampling for water quality parameters at more locations and performing it at more frequent intervals can provide better information on potential trouble spots in the systems. Also, systems can obtain a better spatial representation of the level of these parameters and be able to more accurately assess the potential for metals release in various parts of the system.

Additional water quality and corrosion parameters may be incorporated into baseline monitoring such as measurements of oxidation reduction potential (ORP). ORP is the potential for transfer of electrons between chemical species and is measured in volts (V), millivolts (mV), or Eh (1Eh = 1mV). The ORP of the water can impact the metal oxidation rates and the nature of scales that form on the interior of piping and fittings, affecting metals release.

Kirmeyer et al. (2002) present detailed corrosion control monitoring protocols including both proactive and reactive monitoring objectives.

Usefulness and Limitations

Expanded baseline monitoring can be used to identify areas of a distribution system that have potentially corrosive waters and find areas where a corrosion inhibitor is not performing effectively. An on-going distribution system expanded baseline water quality monitoring program can provide an ‘early-warning’ of potential system-wide problems that may occur after a treatment or operational change, as well as identify the occurrence of more localized water quality problems. Results from this type of monitoring program can also provide a more complete assessment of the system for evaluating the impact of future treatment changes.

References

AWWA 2005a. *Managing Change and Unintended Consequences: Lead and Copper Rule Corrosion Control Treatment*. Denver: AWWA.

Kirmeyer, G.J., J. Clement, and A. Sandvig. 2000a. *Distribution System Water Quality Changes Following Implementation of Corrosion Control Strategies*. AwwaRF Report 90764. Project #157. Denver: AwwaRF.

Kirmeyer, G.J., M. Friedman, K. Martel, G. Thompson, A. Sandvig, J. Clement, and M. Frey. 2002. *Guidance Manual for Monitoring Distribution System Water Quality.* Denver: AwwaRF and AWWA.

USEPA 2002c. Lead and Copper Monitoring and Reporting Guidance for Public Water Systems. Office of Water. EPA 816-R-02-009.

D.2.2 Supplemental Tap Water Quality Monitoring

Description of Method

Supplemental tap water sampling can provide a more complete picture of the occurrence of lead and copper levels at the tap, beyond the information available through regulatory monitoring required by the LCR. Supplemental tap water quality sampling includes collecting LCR samples at more sites and at a greater frequency than required. In addition to traditional LCR sampling, sequential samples can be collected from customer's taps and analyzed to help determine the source of the lead (i.e., whether it is originating from faucets, meters, soldered joints, service lines, plumbing fittings, or other locations). This method is referred to as "water line profiling" or "sequential sampling." Results from profiling can also provide useful information on the relationship of lead and copper corrosion products to other water quality parameters. Analyses of particulate versus dissolved lead can provide information on the possible mechanisms for lead release (e.g., soluble release from metals surfaces or particulate metals release from scales).

Uses and Limitations

Supplemental tap water quality monitoring can provide data that can be used to evaluate the potential impact of treatment and operational changes on lead and copper levels at the tap, and consequently, compliance with the LCR. Additional tap monitoring data on lead and copper levels can provide more confidence in the conclusions with respect to potential impacts system-wide.

Water line profiling can provide diagnostic information on the location of metals release. Results from profiling can also provide useful information on the relationship of lead and copper corrosion products to other water quality parameters. Analyses of particulate versus dissolved lead can provide information on the possible mechanisms for lead release (e.g., soluble release from metals surfaces or particulate metals release from scales).

Because samples are collected at the tap, supplemental monitoring programs require significant cooperation from customers.

References

AWWA. 2005a. M*anaging Change and Unintended Consequences: Lead and Copper Rule Corrosion Control Treatment*. Denver: AWWA.

Boyd, G.R., G.J. Pierson, G.J. Kirmeyer, M. Britton, and R.J. English. 2006. Pb release from end-use plumbing components. Proceedings of *Water Quality Technology Conference.* November 5-9. Denver: AWWA.

Estes-Smargiassi, S., J. Steinkrauss, A. Sandvig, and T. Young. 2006. Impact of Lead Service Line Replacement on Lead Levels at the Tap. In *Proceedings AWWA Annual Conference and Exposition*. San Antonio: AWWA. June, 2006.

Estes-Smargiassi, S., and A. Cantor. 2006. Lead Service Line Contributions to Lead at the Tap. In *Proceedings AWWA Water Quality Technology Conference*. Denver: AWWA. November 2006.

Giani, R., M. Edwards, C. Chung, and J. Wujek. 2004. Lead Profiling Methodologies and Results. Presented at *Getting the Lead Out: Analysis & Treatment of Elevated Lead Levels in DC's Drinking Water at the 2004 AWWA WQTC.* Proceedings of *AWWA Water Quality Technology Conference.* Denver: AWWA.

Kirmeyer, G.J., B.M. Murphy, A. Sandvig, G. Korshin, B. Shaha, M. Fabbricino, and G. Burlingame. 2004b. *Post Optimization of Lead and Copper Control Monitoring Strategies.* AwwaRF Report 90996F Project #2679. Denver: AwwaRF.

D.3 Blending Analysis

Description of Method

Blending analyses can predict the characteristics of the water when two sources are blended in the distribution system and help determine if corrosive conditions might result. While the prediction of some key corrosion parameters can be done using simple mass balance equations, evaluation of others could benefit from the use of computational software. One useful tool is the *Rothberg, Tamburini & Winsor Blending Application Package 4.0* (AWWA 2001a).

Uses and Limitations

Blending analyses can be particularly useful if a water system is considering using an alternative source to comply with a regulation. As with any modeling exercise, the output of the model depends on the accuracy of the input parameters, and users will need a certain level of expertise and understanding of water chemistry and treatment.

References

AWWA. 2001a. The Rothberg, Tamburini & Winsor Blending Application Package 4.0.

AWWA Catalog Number 53042.

Taylor, J.S., J.D. Dietz, A.A. Randall, S.K. Hong, C.D. Norris, L.A. Mulford, J.M. Arevalo, S. Imran, M. Le Puil, S. Liu, I. Mutoti, J. Tang, X. Xiao, C. Cullen, R. Heaviside, A. Mehta, M. Patel, F. Vasquez, and D. Webb. 2005. *Effects of Blending on Distribution System Water Quality*. AwwaRF Report 91065F. Project #2702. Denver: AwwaRF.

D.4 Solubility Models

Description of Method

Chemical solubility models can predict the thermodynamic stability of a given metal under specific water quality conditions and can be used to evaluate the mechanisms underlying scale development and passivation. These models can help in predicting potential corrosion problems and may be especially useful for lead corrosion. There are several non-proprietary and commercially available solubility models, including CORRODE (Edwards and Reiber 1997 a, b) and PHREEQCI (United States Geological Survey).

Uses and Limitations

Solubility models are based on equilibrium kinetics, and may not take into account non-equilibrium conditions and variations in system conditions (particulate lead release, water usage, scale accumulation, etc.) that would impact metals release in the field. A certain level of expertise and understanding of equilibrium chemistry and solubility constants would be needed in order to effectively use these models and evaluate their results properly.

References

Butler, J.N. with a Chapter by David Cogley. 1998. *Ionic Equilibrium. Solubility and pH Calculations.* New York: Wiley-Interscience.

Edwards, M. and S. Reiber. 1997a. *A General Framework for Corrosion Control Based on Utility Experience.* AwwaRF Report 90712A. Project #910. Denver: AwwaRF.

Edwards, M. and S.H. Reiber. 1997b. *Predicting Pb and Cu corrosion by-product release using CORRODE software.* AwwaRF Report 90712B. Project #910. Denver: AwwaRF.

Parkhurst, D.L. and C.A.J. Appelo. 1999. *User's guide to PHREEQC (Version2)—A computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations.* 310 pp. Water Resources Investigations Report 99-4259. U.S. Geological Survey.

D.5 Laboratory and Field Studies

Whereas desktop studies, modeling, and monitoring can provide useful tools for predicting the impact of treatment changes with respect to corrosion, laboratory and field studies can be used to address site-specific issues and in some cases, measure actual changes in corrosion parameters including metals release. This section builds on previous sections by providing information on the following corrosion assessment tools:

- Treatment simulation
- Pipe loop testing
- Coupon studies
- Electrochemical measurement techniques
- Scale and solids analysis
- Partial system testing

D.5.1 Treatment Simulation

Description of Method

Treatment simulation models can used to evaluate the effect of certain treatment changes on corrosion parameters and can be useful in identifying the best combination of treatment scenarios to achieve simultaneous compliance. For example, the *Water Treatment Plant Model* (USEPA 2001i) includes data and alternative treatment processes to assist utilities in achieving optimized conditions. In cases where models may not be sufficient, jar testing can show how treatment changes can alter finished water quality conditions as they relate to corrosion potential.

Uses and Limitations

Jar tests and treatment simulation models are very useful in determining the impact of a treatment change on water quality at the treatment plant. They do not, however, take into account changes as water moves through the distribution system and site specific factors such as microbiological activity and interactions of the water with different pipe material.

References

AWWA. 2000. *Operational Control of Coagulation and Filtration Processes.* 2nd Edition. AWWA Manual M37. pp. 1-34. Denver: AWWA.

AwwaRF. 1999. *Distribution System Water Quality Changes Following Corrosion Control Strategies.* Denver: AwwaRF.

USEPA. 2001i. Water Treatment Plant Model. Version 2.0. Developed by the Center for Drinking Water Optimization, University of Colorado - Boulder and Malcom Pirnie, Inc. May, 2001.

D.5.2 Pipe Loop Studies

Description of Method

Pipe loop studies are intended to simulate corrosion in the consumer's plumbing system and allow for direct measurement of metal release. Pipe loop material can include 1) pipes or pipe sections which reflect actual distribution system conditions with respect to corrosion scale (e.g., pipes extracted from the distribution system), 2) new lead, copper, and/or brass materials representative of new construction, and 3) lead pipes coupled with copper to represent areas where lead service line replacement has occurred.

Pipe loops are typically designed as flow-through or recirculating systems. In flow through pipe loops, water flows through the pipe a single time as in a real system and is discharged to waste. Recirculating pipe loops recirculate the same batch of water through the pipes. In both types, water can be stagnated for periods of time to represent water use patterns. Water from the pipe loops can be collected and analyzed for a variety of water quality parameters including lead, copper, and other corrosion products. Pipes should be conditioned prior to water quality changes to achieve a stable rate of metals leaching.

Uses and Limitations

Pipe loops are well suited for determining how distribution or plumbing materials will respond to changes in water quality and to evaluate potential corrosion control strategies. One advantage is that pipe loops closely simulate actual distribution systems and the conditions under which corrosion occurs. One disadvantage is that these studies can require a relatively long time to conduct and the setups are more expensive than other corrosion assessment techniques. The AwwaRF report titled *Internal Corrosion of Water Distribution Systems* (AwwaRF and DVGW-Technologiezentrum Wasser 1996) contains a thorough description of assessment technologies for corrosion control studies, including a discussion of the benefits and drawbacks of pipe loop studies. AwwaRF reports (Economic and Engineering Services, Inc. and Illinois State Water Survey 1990; Kirmeyer et al. 1994) describe a standard protocol for a pipe loop system for evaluating corrosion control treatment options.

References

AwwaRF and DVGW-Technologiezentrum Wasser. 1996. *Internal Corrosion of Water Distribution Systems.* 2nd Edition. AwwaRF Report 90508. Project #725. Denver: AwwaRF.

Economic and Engineering Services, Inc. and Illinois State Water Survey. 1990. *Lead Control Strategies.* Denver: AwwaRF and AWWA.

Kirmeyer, G.J., A.M. Sandvig, G.L. Pierson, and C.H. Neff. 1994. *Development of a Pipe Loop Protocol for Lead Control.* AwwaRF Report 90650 Project #604. Denver: AwwaRF.

D.5.3 Coupon Studies

Description of Method

Coupon techniques are used to evaluate the corrosion of a given distribution system metal under specific conditions. Coupon techniques place a coupon in water either in a pilot testing apparatus or in the distribution system. The coupons are sacrificed periodically for total weight loss measurements.

Traditional coupon techniques have involved flat metal coupons mounted in a flow stream including methods ASTM D2688-83 method B, ASTM G1-81, ASTM G46-76, and the Water Research Center Coupon Rig. Other techniques have been developed that use actual pipe lengths including ASTM D2688-83 method C, Modified ISWS Coupon sleeve tester, Corps of Engineers Research Lab tester, Ringsaulen protocol, and the TZW Karlsruhe protocol. See Table 9-3 in the publication, *Internal Corrosion of Water Distribution Systems (*AwwaRF and DVGW-Technologiezentrum Wasser 1996), for a summary description of these techniques.

Usefulness and Limitations

Weight loss for lead coupons is generally very low, so interpretation of weight loss data using these methods may be challenging. Coupon techniques are best suited for determining likely corrosion rates that can be expected for given water quality conditions and a given metal, and can be useful in selecting new materials to be used for distribution system expansion or rehabilitation. Weight loss measurements have not always correlated well with measurements of lead release in water samples (Schock 1996). Therefore, the usefulness of this technique for evaluating LCR compliance issues related to lead may be limited, however, they may be of value in evaluating copper corrosion and copper release.

References

ASTM D2688-83 Method B. 1983a. Standard Test Methods for the Corrosivity of Water in the Absence of Heat Transfer (Weight Loss Protocol). Philadelphia: American Society for Testing and Materials.

ASTM D2688-83 Method C. 1983b. Standard Test Methods for the Corrosivity of Water in the Absence of Heat Transfer (Machined Nipple Test). Philadelphia: American Society for Testing and Materials.

ASTM G46-76. 1976. Recommended Practise for the Examination and Evaluation of Pitting Type Corrosion. Philadelphia: American Society for Testing and Materials.

ASTM G1-81. 1981. Recommended Practise for Preparing, Cleaning and Evaluating Corrosion Test Specimens. Philadelphia: American Society for Testing and Materials.

AwwaRF and DVGW-Technologiezentrum Wasser. 1996. *Internal Corrosion of Water Distribution Systems.* 2nd Edition. AwwaRF Report 90508. Project #725. Denver: AwwaRF.

Schock, M. 1996. Corrosion Inhibitor Applications in Drinking Water Treatment: Conforming to the Lead and Copper Rule. Presented at *NACE Corrosion 1996 Conference*.

D.5.4. Electrochemical Measurement Techniques

Description of Method

Corrosion reactions are fundamentally electrochemical reactions which involve the transfer of electrons. Electrochemical methods use different tools and measurement techniques to measure this electron transfer and derive the underlying corrosion rate of a metal. For example, potentiodynamic scans rely on artificial perturbation of the corroding surface by impressing a current on it. Resulting changes in surface potential are measured and used to derive the corrosion rate.

Electrochemical impedance spectroscopy is a relatively new technique that is well suited for drinking water applications. It works similarly to other techniques in that an impressed current is applied to the surface and the resulting potential is measured. It differs from other techniques in that the current is an alternating current instead of a direct current. The results are analyzed to create a model of the corroded surface. This can give a picture of all the components of a corroding surface such as the polarization resistance of the surface and the presence of a passivating layer.

Other electrochemical techniques that may be useful for online monitoring of corrosion include electrical resistance, linear polarization, and electrochemical noise. The 1996 report, *Internal Corrosion of Water Distribution Systems (*AwwaRF and DVGW-Technologiezentrum Wasser 1996*)*, provides a summary of electrochemical corrosion assessment methodologies including their applications, precision, and equipment requirements.

Uses and Limitations

Unlike other evaluation tools which measure metals release, electrochemical techniques provide an instantaneous measurement of the underlying corrosion rate of the metal. They have been shown to be very useful for assessing uniform corrosion of metals such as lead, copper, zinc, and brass (AwwaRF and DVGW-Technologiezentrum Wasser 1996*)*. Over the past decade, there has been substantial development of these techniques, making them more accessible to systems as an operational tool. Advantages of electrochemical techniques include their speed, ease of measurement using commercially available software, and the fact the analyses can be made without changing the test specimen.

Electrochemical methods may be unsuitable for surfaces subject to heavy pitting (i.e. mild steel or iron). These techniques do not reproduce easily across different conditions and are thus more suitable for relative comparisons of corrosion rate rather than measurement of absolute values.

References

AwwaRF and DVGW-Technologiezentrum Wasser. 1996. *Internal Corrosion of Water Distribution Systems.* 2nd Edition. AwwaRF Report 90508. Project #725. Denver: AwwaRF.

Cottis, R.A., S. Turgoose, and R. Newman. 1999. *Corrosion Testing Made Easy: Electrochemical Impedance and Noise.* Houston: National Association of Corrosion Engineers.

Kirmeyer, G.J., B.M. Murphy, A. Sandvig, G. Korshin, B. Shaha, M. Fabbricino, and G. Burlingame. 2004b. *Post Optimization of Lead and Copper Control Monitoring Strategies.* AwwaRF Report 90996F Project #2679. Denver: AwwaRF.

D.5.5 Scale and Solids Analysis

Description of Method

Analysis of pipe scales and corrosion solids can reveal useful information on the corrosion process itself and effectiveness of various corrosion control strategies. Techniques such as X-ray emission spectroscopy, X-ray diffraction, X-ray fluorescence, and scanning electron microscopy can provide information on the elemental composition of the corrosion scales. Some analytical techniques give detailed information on chemical bonding and structure at the surface of the corrosion deposits which is helpful in estimating the probability of unintended adverse consequences of treatment or water quality changes (Rego and Schock 2007).

Uses and Limitations

Pipe surface analyses using the techniques described above can be useful for determining the composition of corrosion scale and corrosion products, and the effectiveness of current treatment practices. Characterization of the corrosion scale can provide insight into the mechanisms behind metals release and how water quality changes may alter that existing scale, potentially resulting in increased metals release. These techniques can also give information on any passivating or barrier layers that can protect pipes from further corrosion. Currently, these methods are relatively expensive and the results can be difficult to interpret. As such, laboratory analyses of corrosion products are typically used for special studies.

References

ASTM D934-80. 2003. Standard Practices for Identification of Crystalline Compounds in Water Formed Deposits by X-Ray Diffraction. Philadelphia: American Society for Testing and Materials.

Clement, J., A. Sandvig, V. Snoeyink, W. Kriven, and P. Sarin.1998. Analyses and Interpretation of the Physical, Chemical, and Biological Characteristics of Distribution System Pipe Scales. In *Proceedings of the Water Quality Technology Conference.* Denver: AWWA.

Rego, C.A. and M.R. Schock. 2007. Case Studies in the Integrated Use of Scale Analyses to Solve Lead Problems. In Proceedings of Distribution System Research Symposium. Denver: AWWA.

Smith, S.E., J.S. Colbourne, D.M. Holt, B.J. Lloyd, and A. Bisset. 1997. An Examination of the Nature and Occurrence of Deposits in a Distribution System and their effect on Water Quality. In *Proceedings of the AWWA Water Quality Technology Conference*. Boston, 17-21 November 17-21. Denver: AWWA.

D.5.6 Partial System Testing

Description of Method

In partial system testing, a corrosion control treatment method is tested on a small part of the distribution system which has been hydraulically isolated from the rest of the system and where water quality conditions can be changed and the impact of that change evaluated. A variety of additional corrosion assessment tools can be used during partial system testing, including:

- Supplemental water quality monitoring from residential taps to evaluate changes in metals release;
- Increased baseline monitoring of key water quality parameters;
- Inserting coupons into the distribution system that can be removed and analyzed;
- Electrochemical monitoring using on-line devices; and
- Removal of piping materials for evaluation of the corrosion scale.

An outreach program should be in place to the customers in that section of the distribution system informing them of the test and any changes which they might experience.

Uses and Limitations

A partial system test can be very useful in examining system specific issues which might not be obvious from pipe loop tests or other laboratory techniques. For example, partial system tests can help determine whether a given water quality change might lead to red water incidents within the system.

A partial system test, however, does not guarantee that problems will not occur in the rest of the system as there can still be differences in piping material, water temperatures, soil conditions, pipe age and other variables. A partial system test will also require isolating that part of the system and communicating closely with customers in that portion of the system. It may also require setting up temporary chemical feed facilities, which can be quite expensive and difficult to control operationally due to fluctuations in flow.

References

AwwaRF and DVGW-Technologiezentrum Wasser. 1996. *Internal Corrosion of Water Distribution Systems.* 2nd Edition. AwwaRF Report 90508. Project #725. Denver: AwwaRF.

Kirmeyer, G.J., J. Clement, and A. Sandvig. 2000a. *Distribution System Water Quality Changes Following Implementation of Corrosion Control Strategies*. AwwaRF Report 90764. Project #157. Denver: AwwaRF.

USEPA. 1992b. Lead and Copper Rule Guidance Manual, Vol. II: Corrosion Control Treatment. Prepared by Malcolm Pirnie, Inc. & Black & Veatch. September 1992.

Appendix E

Innovative Management Tools for Achieving Simultaneous Compliance

Appendix E
Innovative Management Tools for Achieving Simultaneous Compliance

Systems simultaneously complying with the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR), Stage 2 Disinfectants and Disinfection Byproducts Rule (DBPR), and other drinking water regulations may benefit from a broader, more holistic approach to water system management. Therefore, EPA and other organizations are developing integrated, source-to-tap management programs to assist water systems. These programs can provide a framework within which water systems can identify simultaneous compliance concerns, prioritize them, and adopt approaches to ensure that they will be in compliance with numerous regulations at the same time.

This appendix identifies existing and developing programs that can help water systems comply with regulations and produce consistently high quality water. These programs include performance-driven and integrated management approaches that consider treatment processes and operating practices throughout the entire water system. Systems are encouraged to consult with primacy agencies and other systems with similar treatment facilities and water quality to aid in carrying out these programs.

Performance-Driven Optimization Programs

Several programs have been developed for water systems to optimize treatment plant performance and distribution system management. This section briefly describes these programs including references for more detailed information.

Partnership for Safe Water

The Partnership for Safe Water is a voluntary program organized collaboratively amongst EPA, AWWA and other drinking water organizations to optimize water treatment plant performance above and beyond regulatory requirements. The Partnership has provided a successful approach for systems to improve turbidity removal in their treatment plants and reduce microbial risks as addressed in the surface water treatment rules. The Partnership's Information Center, (http://www.awwa.org/science/partnership/InfoCenter/) includes self-assessment checklists, sample reports and fact sheets to help a water system get started.

QualServe

QualServe is a continuous quality improvement program that helps utilities to improve overall service using a self-assessment tool, a peer review process, and a benchmarking clearinghouse. The self-assessment tool is a survey of utility employees to gauge their opinions and get their buy in and support for improvements. The peer review involves an on-site visit and evaluation by a volunteer team of peers from other utilities. Benchmarking is used to track utility performance and compare it to other utilities, thereby learning from their experiences. Additional information can be found on AWWA's website (http://www.awwa.org/science/qualserve/).

Areawide Optimization Program

An area-wide optimization program (AWOP) is a multi-state effort in which states work together to develop and implement individual state programs to optimize particle removal and disinfection capabilities of conventional surface water treatment plants in each state (http://www.asdwa.org/index.cfm?fuseaction=Page.viewPage&pageID=523). AWOP is designed to assist water systems work toward optimizing their existing treatment processes in an effort to increase public health protection. While originally developed to address microbial contaminants, AWOP has expanded beyond the original tools and is an ever-changing and ever-growing program that now addresses both microbial contaminants and disinfection byproducts in surface water systems. Initial steps are also being taken to investigate how to extend the optimization concept to ground water systems. More information is available at the Association of State Drinking Water Administrators (ASDWA) website listed in this paragraph.

Microbial and DBP Comprehensive Performance Evaluations

A comprehensive performance evaluation (CPE) is the evaluation phase of EPA's Composite Correction Program. A Composite Correction Program is a systematic, comprehensive procedure that identifies and corrects a unique combination of factors to improve performance at filtration plants using existing facilities. CPEs are designed to identify and correct limiting factors in the design, operation, maintenance, and administration of public water systems that prevent compliance with drinking water regulations and optimized water system operation. CPEs help systems prioritize ways to improve water system operation, and often provide options without significant capital improvements as the highest priority option. CPEs are designed to ensure that water systems consistently produce high quality drinking water.

While CPEs have primarily addressed pathogen control, efforts are underway to develop a CPE methodology that addresses DBP control. A CPE for microbes or disinfection byproducts (DBPs) consists of three components: performance assessment, major unit process evaluation, and identification of factors that are limiting performance. The performance assessment component determines a facility's status in achieving compliance for microbial and DBP compliance requirements and performance goals and verifies the extent of any performance problems at the plant. The major unit process evaluation determines if the various key existing treatment processes in the plant, if properly operated, are of sufficient size to meet microbial and DBP performance goals at the plant's current peak instantaneous operating flows. The last and most significant component of a CPE is the identification of factors that limit the plant's performance. CPEs are often conducted with the aid of primacy agency personnel or consultants.

For more information on CPEs, please see:

Association of State Drinking Water Administrators. 2005. Total System Optimization – How Does it Relate to AWOP? Area-Wide Optimization Program News. 2(1). March 2005. Contact Alison Dugan at *dugan.alison@epa.gov* or Larry DeMers at *LDemersCO@aol.com*. http://www.asdwa.org/index.cfm?fuseaction=Page.viewPage&pageID=523

Center for Drinking Water Optimization Page (University of Colorado at Boulder) *http://bechtel.colorado.edu/cdwo/Welcome.html*

EPA's Drinking Water Academy Web site has numerous courses on conducting CPEs. *http://www.epa.gov/safewater/dwa/course-pwsoper.html*

USEPA. 1998a. Handbook: Optimizing Water Treatment Plant Performance Using the Composite Correction Program. EPA 625/6-91/027. *http://www.epa.gov/ORD/NRMRL/pubs/625691027/625691027.htm*

Hegg, B.A. and L.D. DeMers. 2003. Performance Based Training: A Proven Approach to Improve Water Treatment Plant Performance. Presented at *American Water Works Annual Conference*. Anaheim, California. (June 15-19, 2003).

Jeschke, Rick, P.E. Plant Optimization at North Table Mountain Water and Sanitation District. Presented at the 2004 Joint Annual Conference of the Rocky Mountain Section of the American Water Works Association and the Rocky Mountain Water Environment Association. Grand Junction, Colorado. *http://www.rmwea.org/tech_papers/Admin-finance/NTM_PPT_Pres.ppt*

Kentucky Division of Water. Area Wide Optimization Program. *http://www.water.ky.gov/dw/profi/awop/default.htm*

Swanson, Warren J., P.E. Assessing Plant DBP Performance Using the DBP-CPE. Presented at the 2004 Joint Annual Conference of the Rocky Mountain Section of the American Water Works Association and the Rocky Mountain Water Environment Association. Grand Junction, Colorado http://www.rmwea.org/tech_papers/Admin-finance/DBPCPE_final.ppt

USEPA. 2004c. The Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR) Implementation Guidance. (Appendix C) EPA 816-R-04-008.

USEPA. 2002c. Comprehensive Performance Evaluation (CPE): The Basics (Brochure). (EPA 816-F-01-020). November 2002.

USEPA. 1999d. Guidance Manual for Compliance with the Interim Enhanced Surface Water Treatment Rule: Turbidity Provisions. EPA 815-R-99-010.

USEPA. 1998. CPE Training CD Optimizing Water Treatment Plant Performance Using the Composite Correction Program. EPA 625/6-91/027.

USEPA. 1998. Introduction to Comprehensive Performance Evaluations. EPA/625/C-01-011.

USEPA. Area Wide Optimization Program. http://www.epa.gov/reg3wapd/drinkingwater/optimization/

Integrated Management Systems

It can be challenging for water systems to consider the impacts of specific management or operations decisions on their entire water system. Efforts have been made to develop or adopt management programs that consider the entire water system. For example, ISO 9000 addresses general quality management issues, ISO 14001 focuses on protection of the environment, and HACCP addresses drinking water safety to the consumer. Most of these programs serve as frameworks that managers can use to tailor a source-to-tap management program addressing issues and concerns specific to their water system. Because this approach is holistic (source-to-tap), such programs can serve as effective ways to consider simultaneous compliance issues. Integrated management systems are becoming a new trend in the water industry where these programs are considered in an integrated manner as one quality assurance system that covers all business management aspects, including general quality management (ISO 9000), protection of the environment (ISO 14001), drinking water safety to the user (HACCP), and worker health and safety. The benefit of implementing one integrated system is that only one audit would be required and utility staff will implement only one set of policies and procedures (Martel et al. 2006). The AwwaRF report, *Application of HACCP for Distribution System Protection* (Martel et al. 2006) describes utility experiences with implementing integrated management systems. This section briefly describes these management programs that, if used properly, could help a system achieve simultaneous compliance.

Hazard Analysis and Critical Control Point

The Hazard Analysis and Critical Control Point (HACCP) program is an integrated risk management approach that examines and assesses potential sources of contamination to a process and develops control measures to mitigate these risks. HACCP has been used by the U.S. Food and Drug Administration for years, and has become an accepted management practice internationally to ensure the safety of food. Recent research indicates that HACCP principles may be successfully applied to drinking water systems (Martel et al. 2006). This information may then be used by drinking water systems to reduce the risk of contamination to the general public. A HACCP Plan can be created and implemented by utility staff with appropriate knowledge of the chemical, physical, and microbiological hazards in water supplies, and the control measures used to manage them. Although outside experts are sometimes utilized as advisors to the HACCP team, development of the HACCP Plan should be driven by utility staff as successful implementation of the HACCP Plan requires buy-in and support at all levels of the organization.

Seven basic principles are employed: hazard analysis; critical control point identification; establishing critical limits; monitoring procedures; corrective actions; verification procedures; and record-keeping and documentation. If a deviation occurs that indicates a loss of control, the water system detects the deviation and takes the appropriate, defined steps to reestablish control in a timely manner and ensure that potentially contaminated water does not reach the consumer and cause compliance problems with one or more regulation.

For additional information on HACCP, please refer to the following resources:

AIChE. 2000. Guidelines for Chemical Process Quantitative Risk Analysis, Second Edition. Wiley.

Dewettinck T., E. Van Houtte, D. Geenens, K. Van Hege, and W. Verstraete. 2001. HACCP (Hazard Analysis and Critical Control Points) to Guarantee Safe Water Reuse and Drinking Water Production--a Case Study. Water Science & Technology. 43(12): 31-8.

Martel, K., G. Kirmeyer, A. Hanson, M. Stevens, J. Mullenger, and D. Deere. 2006. *Application of HACCP for Distribution System Protection*. AwwaRF Project #2856. Denver, CO: AwwaRF.

Mullenger, J., G. Ryan, and J. Hearn. 2002. A Water Authority's Experience with HACCP. *Water Supply*. 2(5-6): 149-155. ©© IWA Publishing.

U.S. Food and Drug Administration. 1997. Hazard Analysis and Critical Control Point Principles and Application Guidelines. *http://www.cfsan.fda.gov/~comm/nacmcfp.html*

U.S. Food and Drug Administration Website. *http://www.cfsan.fda.gov/~lrd/haccp.html*

World Health Organization. 2004. Water Treatment and Pathogen Control: Process Efficiency in Achieving Safe Drinking Water. Edited by M.W. LeChevallier and K.K. Au. ISBN: 1 84339 069 8. Published by IWA Publishing, London, UK.

World Health Organization. 2004. Guidelines for Drinking Water Quality, 3rd Edition. Geneva, Switzerland. World Health Organization.
http://www.who.int/water_sanitation_health/dwq/gdwq3rev/en/index.html

ISO 9001 and 14001

The International Organization for Standardization (ISO) is the internationally recognized source of standards that are commonly applied in Europe, Australia, and Asia. Two ISO Standards commonly employed by water utilities include ISO Standards 9001 and 14001. ISO Standard 9001 defines a Quality Management System that demonstrates the ability of an organization to consistently provide products and services that meet customer needs, regulatory requirements and internal goals. ISO Standard 14001 provides management system standards that businesses, including drinking water systems, may use to minimize adverse impacts on the environment, and to continually improve environmental performance, enabling them to simultaneously comply with multiple objectives. ISO 14001 is typically implemented by a system's management staff, possibly with the aid of consultants.

For more information on ISO 14001 please see:

American National Standards Institute (ANSI) Website. http://web.ansi.org /

Global Environment & Technology Foundation. Implementing Environmental Management Systems (EMS) in Public Entities. http://www.getf.org/projects/muni.cfm

Global Environment & Technology Foundation. 2002. Final Report: Second EMS Initiative for Government Entities (2000-2002). Annandale: GETF.

Global Environment & Technology Foundation. 2000. Final Report: The EPA Environmental Management System Pilot Program for Local Government. Annandale: GETF.

Grant, G., B.Sc., CEA, EMS(LA), CEAS. 2004. ISO 14001 and Drinking Water Quality. Environmental Science and Engineering. January, 2004. http://www.esemag.com/0104/xcg.html

International Organization for Standardization. http://www.iso.org

ISO 1400 Information Center. http://www.iso14000.com/

NSF International. 1996. NSF International Environmental Management System Demonstration Project - Final Report.

Pennsylvania's Multi State Working Group Pilot. 1999. The Effects of ISO 14001 Environmental Management Systems on the Environmental and Economic Performance of Organizations. March 27, 1999. http://www.dep.state.pa.us/dep/deputate/pollprev/Tech_Assistance/mswgreport1.htm

Redaud, J.L. 2005. ISO/TC 224 "Service Activities Relating to Drinking Water Supply Systems and Wastewater Systems - Quality Criteria of the Service and Performance Indicators". ISO. March 31, 2005. http://www.pacinst.org/inni/WATER/ISOTC224Description.pdf

Roig, R. and A. Saponara. 2003. ISO 14001 Environmental Management Systems: A Complete Implementation Guide. ISO. Available for purchase from: http://www.stpub.com/pubs/allpubs.htm

USEPA Web site. Voluntary Environmental Management Systems/ISO 14001. http://www.epa.gov/owm/iso14001/

USEPA Mid-Atlantic Region Web site. http://www.epa.gov/region3/ems/emslinks.htm

Additional Resources

AWWA. 1999d. *Design and Construction of Small Water Systems*. 2nd Edition. 228 pp. Denver: AWWA.

Logsdon, G.S., A.F. Hess, M.J. Chipps, and A.J. Rachwal. 2002. *Filter Maintenance and Operations Guidance Manual.* AwwaRF Report 90908. Project #2511. Denver: AwwaRF.

Lauer, B. 2001. *Self-Assessment for Treatment Plant Optimization, International Edition*. AWWA Publication. 256 pp. Denver: AWWA.

Renner, R.C. and B.A. Hegg. 1997. *Self-Assessment Guide for Surface Water Treatment Plant Optimization.* AwwaRF Report 90736. Project #274. Denver: AwwaRF.

Smith, C.D. (editor). 2005. *Water Distribution System Assessment Workbook*. 85 pp. Denver: AWWA.

Westerhoff, G.P., D. Gale, P.D. Reiter, S.A. Haskins, J.B. Gilbert, and J.B. Mannion. 1998a. *The Changing Water Utility: Creative Approaches to Effectiveness and Efficiency*. Denver: AWWA.

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Appendix F

Considerations for Systems Complying with the Ground Water Rule

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Appendix F
Considerations for Systems Complying with the Ground Water Rule

Ground water systems will likely face challenges similar to those faced by surface water systems when making treatment or operational changes to comply with the Stage 2 DBPR. Unique challenges, however, may emerge when systems make treatment or source changes to comply with the Ground Water Rule (GWR), particularly when adding a disinfectant for the first time. This appendix focuses on these unique challenges for systems complying with the GWR, referring to the main body of this guidance manual for additional information as appropriate.

This appendix begins with a brief overview of the GWR, focusing on the provisions that involve a decision to add or change treatment, or to change to an alternate source of water. This overview is followed by a discussion of corrective actions that could potentially create simultaneous compliance issues, followed by more detailed discussion of the issues for each type of corrective action. A list of references where the reader can find additional information is presented at the end of this appendix and in Chapter 7 of this manual.

Additional guidance on complying with the GWR will be included in the following EPA publications:

- Complying with the Ground Water Rule: Small Entity Compliance Guide
- Consecutive System Guide for the Ground Water Rule
- Ground Water rule Corrective Action Guidance Manual
- Ground Water Rule Source Water Monitoring Guidance Manual
- Ground Water Rule Source Water Assessment Guidance Manual
- Ground Water Rule Sanitary Survey Guidance Manual
- The Ground Water Rule Implementation Guidance

These guidance manuals are under development and will be posted on EPA's website when they are complete. (http://www.epa.gov/safewater/disinfection/gwr/compliancehelp.html)

F.1 Overview of the Ground Water Rule

The GWR applies to all public water systems (PWS) serving ground water (except those serving only ground water under the direct influence of surface water) including:

- Wholesale systems that supply ground water;

- Consecutive systems that buy ground water; and

- Mixed systems that use both surface water and ground water (except systems that blend all of their ground water with surface water or ground water under the direct influence of surface water prior to treatment under the Surface Water Treatment Rules).

The GWR uses a targeted risk-based approach for systems susceptible to fecal contamination and employs four major components:

- Periodic sanitary surveys
- Source water monitoring
- Corrective action
- Compliance monitoring

Under the GWR, a system is required to take corrective action if it is found to have a significant deficiency. Significant deficiencies are defined by the states, and may be found during sanitary surveys or at another time when a regulator is visiting a system. If a system is found to have a significant deficiency it must do at least one of the following:

- eliminate the source of contamination;
- correct the significant deficiency;
- provide an alternate source of water; and/or
- provide treatment that achieves 4-log virus inactivation or removal.

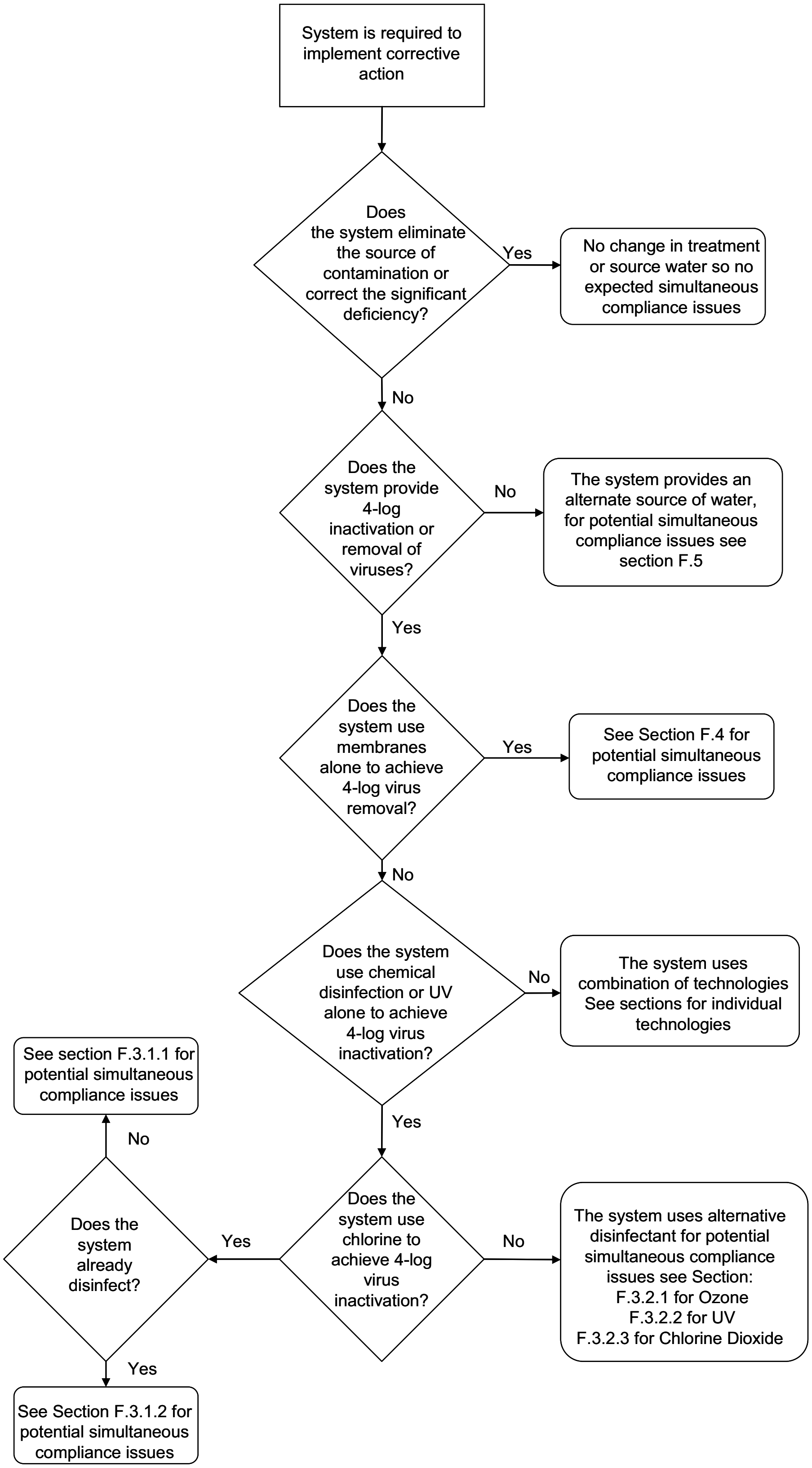
Systems that choose to provide 4-log virus inactivation or removal or that already provide such inactivation or removal must monitor to demonstrate 4-log virus inactivation or removal.

Systems may also be required to undertake actions as a result of monitoring. Under the GWR triggered monitoring requirements, systems that experience a positive total coliform sample during TCR monitoring are required to monitor their source water for a fecal indicator. In addition, states may require source water assessment monitoring on a monthly basis for a fecal indicator. If a system detects a fecal indicator via either process, it may be required by the state to take five additional source water samples and have them analyzed for a fecal indicator. Alternatively, a state may require the system to take corrective action without collecting the additional samples. If any of the five additional samples are positive for the fecal indicator, the system must take corrective action by either eliminating the source of contamination, providing an alternate source of water, or providing treatment that achieves 4-log virus inactivation or removal. Systems that choose to provide 4-log virus inactivation or removal or that already provide such inactivation or removal must monitor to demonstrate continuing 4-log virus inactivation or removal.

F.2 Corrective Actions of the Ground Water Rule That Could Create Simultaneous Compliance or Operational Issues

The corrective action provisions involve a decision-making process about treatment, source water, and other actions such as eliminating the contamination source or correcting a significant deficiency as illustrated in Exhibit F.1. The remainder of this appendix provides information for systems that may be implementing corrective actions involving new treatment, a treatment change, or an alternate source of water. It is these systems that are more likely to face simultaneous compliance challenges and other operational issues as the GWR is implemented.

Exhibit F.1 Decision Tree for Identifying Potential Simultaneous Compliance Issues Associated with GWR Corrective Actions



F.3 Inactivation Using Disinfection

Inactivation through disinfection is one of several possible corrective actions that could be implemented by ground water systems with significant deficiencies or fecal contamination. Systems can use free chlorine or a state-approved alternative disinfection technology (40 CFR 141.403(a)(6)(iv)). The dose required will be set by the state using either existing CT tables or state approved alternatives. Exhibit F.2 summarizes EPA's recommended CT values to achieve 4-log virus inactivation using the various chemical disinfectants. For UV, the required dose for 4.0-log inactivation of viruses is 186 millijoules per centimeter squared (mJ/cm^2) (40 CFR 141.720(d)(1)).

Exhibit F.2 CT Values for Inactivation of Viruses Using Different Disinfectants (min*mg/L), pH range 6 - 9

Disinfectant	***Temperature (^{o}C)***					
	≤1	***5***	***10***	***15***	***20***	***25***
Chlorine	12	8	6	4	3	2
Chlorine Dioxide	50.1	33.4	25.1	16.7	12.5	8.4
Ozone	1.8	1.2	1.0	0.6	0.5	0.3

Source: USEPA 1991

In some cases, systems will already be disinfecting but will need to increase disinfectant dose or contact time before the first customer to provide 4-log inactivation of viruses. In other cases, systems may be disinfecting for the first time. A ground water system that initiates chemical disinfection will be required to meet the Stage 2 DBP Rule (and possibly the Stage 1 DBPR depending on timing). In addition, systems may face LCR or TCR challenges in balancing disinfectant selection, CT requirements, etc. Simultaneous compliance issues specific to chlorine and alternative disinfectants are discussed in Sections F.3.1 and F.3.2, respectively. Section F.3.1 addresses potential issues for those systems initiating chlorine as well as those systems increasing chlorine dose or CT.

F.3.1 Chlorine

Because chlorine is not a technology that systems will use for LT2ESWTR compliance, chlorination is not discussed separately in the main text of this Simultaneous Compliance Guidance Manual. Instead, it is used as the baseline for comparison to other disinfection technologies. Some ground water systems, however, will either begin chemical disinfection using free chlorine, or will increase CT by increasing the free chlorine dose or contact time as a corrective action for the GWR. Thus, a brief description of chlorination and an overview of its simultaneous compliance issues are provided below.

Chlorination is the oldest disinfection process used to treat drinking water. This process utilizes free chlorine to kill most bacteria, viruses, and other pathogens. Chlorine may be introduced into water in the form of gas, sodium/calcium hypochlorite (tablets, solutions, or powder), and other compounds. Free chlorine refers to the chlorine that is not combined with ammonia or organic nitrogen in the water (i.e., elemental chlorine gas (Cl_2), hypochlorous acid, and hypochlorite). A free chlorine residual may remain in the water after adequate CT has been achieved and thus provide for residual (or secondary) disinfection throughout a water distribution system. Residual disinfection can help control biofilm growth in the distribution system and protect against pathogen intrusion through cross connections, infiltration, or line breaks.

A free chlorine residual impacts water chemistry in a number of ways that are important for water treatment. It increases the oxidation-reduction potential (ORP) of the receiving water. The consequences of this effect are system-dependent (White 1999) and subsequently may either be advantageous or not. ORP can control the reactions on the surface of pipes, including the formation of passivating scales. Changes in ORP can lead to alteration of these reactions and release of metals. Lytle and Schock (2005) discovered a change in ORP could cause changes to lead-containing scales and release of lead into the water. Chlorine addition also affects pH; chlorine gas decreases pH while sodium or calcium hypochlorite increases pH (White 1999). Both pH and total alkalinity of water after chlorination must therefore be taken into careful consideration.

In general, systems using chlorine to disinfect may have to contend with the following issues:

- Chlorinated DBP (TTHM and HAA5) formation
- Compliance with free chlorine MRDL of 4.0 mg/L (40 CFR 141.65(b)(1))
- Taste and odor concerns
- Change in pH
- Change in ORP
- Increased corrosivity towards iron and copper (Cantor et al. 2003)

F.3.1.1 Initiating Chlorination

The initiation of disinfection using free chlorine can alter the water chemistry entering the distribution system. All of the simultaneous compliance considerations described in section 3.1 of this appendix apply to most surface water, ground water, and blended water sources.

However, there are some special considerations with regard to initiating disinfection or increasing disinfectant dose when using free chlorine for ground water systems.

Ground water sources are often anoxic, or contain very low levels of dissolved oxygen. Addition of free chlorine can cause a significant increase in the redox potential of the water, which in turn can cause precipitation of dissolved constituents in the source water, and/or oxidation and precipitation of dissolved constituents in corrosion scales. Precipitation can lead to discolored water reaching the customer's tap.

Introduction of a disinfectant residual into the distribution system and the subsequent destabilization of corrosion scales can result in sloughing of established biofilms. Release of biofilm organisms could impact TCR compliance. Over the long term, however, a disinfectant residual is expected to achieve better control over microbial growth (USEPA 2002e) and improve TCR compliance.

The form of free chlorine used for treatment can impact the pH of the finished water, depending on the buffering capacity. The use of chlorine gas (hypochlorous acid) can lower the pH and the use of sodium hypochlorite can increase the pH. Generally, ground water supplies have greater buffering capacity compared to surface water supplies. Thus, pH impacts may be less for ground water systems. Potential simultaneous compliance issues associated with decreasing pH are discussed in Section 3.4 of the main text of this guidance manual. Increasing the pH in ground water systems may enhance precipitation of dissolved metals such as iron and manganese. Increasing the pH may also decrease the adsorptive capacity of iron scales for arsenic, resulting in increased arsenic levels at the tap.

For ground water systems with low dissolved oxygen (DO), adding chlorine has a similar effect on copper corrosion as increasing DO. Consequently ground water systems that implement disinfection with chlorine may experience increased copper corrosion and LCR compliance challenges. High alkalinity/dissolved inorganic carbon (DIC) ground water systems are also susceptible to increased copper corrosion which may be exacerbated when a chlorine residual is present (USEPA 2003h; Schock and Fox 2001).

If organic material is present in the groundwater, adding a disinfectant can form DBPs. If the organic concentration is high enough there could be problems complying with the Stage 2 DBPR (or Stage 1 DBPR depending on the timing). Systems with high organic carbon concentrations in their groundwater may need to consider an alternative disinfectant or remove the organic carbon to keep DBP levels under the Stage 2 DBPR MCL.

F.3.1.2 Increasing Chlorine Dose or Contact Time

Increasing the chlorine dose can also increase the redox potential of water, which can cause precipitation of dissolved constituents in the distribution system, and/or oxidation and precipitation of dissolved constituents in corrosion scales. Increasing the chlorine dose or contact time to achieve CT would most likely have less of this effect than when a system adds disinfection for the first time.

If a ground water source contains organic material, TTHM and HAA5 levels may increase when the chlorine dose is increased, potentially causing problems with compliance with the Stage 2 DBPR (or the Stage 1 DBPR depending on timing). Increasing chlorine contact time prior to the first customer may be a lesser impact on TTHM and HAA5 formation than increasing chlorine dose.

F.3.2 Alternative Disinfectants

Chapter 5 of this manual presents simultaneous compliance and operational issues associated with initiation of chlorine dioxide, ozone, and UV for both surface and ground water systems. Some additional considerations for ground water systems are provided below.

F.3.2.1 Ozone

Some ground water systems may face challenges in meeting the bromate MCL. As discussed in Section 5.2 of this manual, ozone can react with bromide in the source water to form bromate, which has an MCL of 10 ppb under the Stage 1 D/DBPR. Ground water sources generally have higher levels of bromide than surface waters (USEPA 1999j). Consequently ground water systems may face more difficulty in complying with the bromate MCL under the Stage 1 and Stage 2 D/DBPR.

Ground water sources are often anoxic, or contain very low levels of dissolved oxygen. Addition of ozone can cause a significant increase in the redox potential of the water, which in turn can cause precipitation of dissolved constituents in the source water, and/or oxidation and precipitation of dissolved constituents in corrosion scales. Precipitation can lead to discolored water reaching the customer’s tap.

Ozonation is a more complex treatment process (compared to liquid feed systems such as hypochlorite) which may pose implementation challenges for ground water systems with multiple wells.

Ozonation increases AOC levels. AOC acts as a food source for microbes and can lead to increased microbial growth within the distribution system and potential simultaneous compliance issues with the TCR, especially for ground water systems that do not provide a disinfectant residual. EPA recommends that systems consider AOC reduction through use of biological filtration prior to water entering the distribution system.

F.3.2.2 UV Disinfection

Simultaneous compliance issues associated with adding UV disinfection are discussed in Section 5.3 of this guidance manual. This section presents special considerations for ground water systems adding UV to achieve 4-log virus inactivation for the GWR.

As noted in Section 5.3, the UV dose needed for 4-log inactivation of viruses is very high. At present, EPA is unaware of available challenge testing procedures that can be used to validate the performance of UV reactors at dose levels needed for this level of virus inactivation.

EPA recommends, therefore, that UV technology be used in a series configuration or in combination with other technologies to provide a total 4-log treatment of viruses to meet the GWR's requirements.

Dissolved minerals such as iron, manganese, and calcium can impact the disinfection effectiveness of UV and cause fouling of the UV lamp sleeves. Because ground waters typically have higher dissolved mineral content, systems using ground water may face these problems more frequently than surface water systems.

When UV disinfection is applied to water with a free or total chlorine residual, some reduction of the residual may occur. The reduction in free chlorine residual is proportional to the delivered dose and independent of flow rate (Brodkorb and Richards 2004; USEPA 2006b). The reduction in total chlorine residual is also proportional to the delivered dose (Wilczak and Lai 2006). Ground water systems that already provide a disinfectant residual will need to consider the appropriate placement of the UV disinfection system.

UV systems tend to be more sensitive to power quality than pumping equipment. It is possible that the UV system lamps could lose arc, but the pumping system is unaffected, and then untreated or inadequately treated water can pass through the system. This could be a concern for ground water systems that do not provide residual disinfection. Additionally, because ground water systems typically involve pumping, there may be issues with hydraulic surge and negative pressures. Careful design and operation are important to address these issues.

F.3.2.3 Chlorine Dioxide

Chlorine dioxide dose is limited both by the MRDL of 0.8 mg/L, and the chlorite MCL of 1.0 mg/L under the Stage 1 DBPR. The dose restrictions and relatively high CT for chlorine dioxide, compared to chlorine, under cold water conditions may mean additional new infrastructure such as a clearwell is necessary for ground water systems to allow sufficient contact time to meet 4-log virus inactivation requirements.

As discussed in Section 5.4 of this manual, systems using chlorine dioxide must monitor daily at entry points to the distribution system. Some ground water systems may have multiple entry points thereby increasing overall monitoring requirements, which may be especially challenging for small ground water systems.

Also as discussed in Section 5.4, chlorine dioxide is a strong oxidant and can oxidize iron, arsenic, and other inorganics present in source water, causing precipitants to form. Ground water sources can have higher levels of these and other inorganic constituents compared to surface water systems.

F.4 Membrane Processes

Simultaneous compliance issues and operational concerns associated with using membranes to treat surface water and ground water are described in detail in Sections 4.2 and 4.3 of this guidance manual. Specific considerations when using membrane processes for virus removal from groundwater are described here. Items of interest stem primarily from the removal of constituents from the feed water and are thus highly dependent on the properties of the membrane(s) used and should be considered accordingly.

Membrane systems generally require some form of pretreatment to minimize fouling and reduce the number of cleaning periods required. Typically some form of media filtration precedes a membrane process, particularly for NF and RO membranes. The type of pretreatment process used is primarily dictated by the groundwater chemistry, specifically regarding hardness, iron, manganese, calcium, magnesium, sulfate, and silica.

Anoxic groundwater sources that become exposed to the atmosphere during pumping or aeration may result in the mineral precipitation and membrane scaling. Systems that aerate the groundwater to oxidize the iron, manganese, or other compounds must remove the precipitated minerals before they reach the membrane unit to reduce fouling and scaling.

Reductions in pH, hardness, alkalinity, and other minerals may upset the distribution system chemical equilibrium, causing corrosion and/or scale destabilization. This may lead to compliance issues with the LCR. Post-treatment of membrane product waters may be required for those treated using NF and RO membranes to reduce the corrosivity of the water.

Before installing membranes, ground water systems should be sure to factor in increased capital and O&M costs associated with pre- and post-treatment requirements, especially for ground water systems with multiple wells.

F.5 Selection of an Alternative Source

A ground water system may decide to provide an alternate source of water as a corrective action under the GWR. Selecting an alternative source may be more technically and economically feasible than other corrective actions using the existing source.

Ground water systems considering an alternate source as their corrective action for the GWR will face similar challenges to systems that select an alternate source to comply with the Stage 2 DBPR or LT2ESWTR. These issues are discussed in section 3.1 of this guidance manual and summarized below.

- Blending of different waters when only one of multiple sources is replaced;

- Changes in water quality parameters (WQPs) such as DO, temperature, pH, alkalinity/DIC, redox potential, turbidity, NOM/TOC, dissolved iron and manganese, and the presence of other contaminants and need for additional treatment;

- Impact of the change in WQP on corrosion control for LCR compliance, DBP formation (if already disinfecting), or AOC levels that might impact TCR compliance;

- Introduction of new contaminants or higher concentrations of existing contaminants (e.g., iron, manganese, hydrogen sulfide);

- A change in raw water pH that could adversely affect water treatment and compliance with the LCR;

- For GWR systems that are already disinfecting, an alternate source water under reduced conditions (e.g., little or no dissolved oxygen) may exert increased disinfectant demand; and

- Changes in aesthetic quality may generate customer complaints.

References

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